

# **New Hampshire Water Resources Research Center Annual Technical Report FY 2013**

# Introduction

The New Hampshire Water Resources Research Center (NH WRRC), located on the campus of the University of New Hampshire (UNH), is an institute that serves as a focal point for research and information on water issues in the state. The NH WRRC actually predates the Federal program. In the late 1950s Professor Gordon Byers (now retired) began a Water Center at UNH. This Center was incorporated into the Federal program in 1965 as one of the original 14 state institutes established under the Water Resource Research Act of 1964. The NH WRRC is currently directed by Ms. Michelle Daley (Interim Director) with administrative and technical assistance from Jody Potter (Water Quality Analysis Lab (WQAL) Manager). The NH WRRC is a standalone organization, in that it is not directly affiliated with any other administrative unit at UNH, and it reports to the Dean of the College of Life Sciences and Agriculture (COLSA). The NH WRRC has no dedicated laboratory or research space, and instead relies on space allocated for the research activities of the WRRC director by COLSA. The NH WRRC does have administrative space on campus, which houses the Associate Director, WRRC files, and short-term visiting staff and graduate students. The WRRC website ([www.wrrec.unh.edu](http://www.wrrec.unh.edu)) serves as a focal point for information dissemination and includes all NH WRRC publications and results from past research, as well as links to other sites of interest to NH citizens and researchers.

## Research Program Introduction

The NH WRRC supported three research projects with its 2013 104b funding:

1. Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds
2. Arsenic chemical dynamics in NH groundwater reservoirs: Insights from temporal variability in multi-element signatures of statewide samples
3. James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response

The Water Quality Analysis Lab (WQAL) is affiliated with the NH WRRC and facilitates water resources research through technical assistance and sample analysis. The WQAL was established by the Department of Natural Resources in 1996 to meet the needs of various research and teaching projects both on and off the UNH campus. It is currently administered by the NH WRRC and housed in James Hall. The mission of the Water Quality Analysis Laboratory is to provide high-quality, reasonably priced analyses in support of research projects conducted by scientists and students from throughout the University, state, and nation. Past clients have included numerous research groups on the UNH campus, Federal agencies, scientists from other universities, and private firms. Many thousands of analyses are conducted each year.

# Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds

## Basic Information

<b>Title:</b>	Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds
<b>Project Number:</b>	2003NH21B
<b>Start Date:</b>	3/1/2013
<b>End Date:</b>	2/28/2014
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	NH01
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Non Point Pollution, Surface Water, Nutrients
<b>Descriptors:</b>	
<b>Principal Investigators:</b>	William H. McDowell

## Publications

1. Buyofsky, L.A. 2006. Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed. M.S. Dissertation, Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH
2. Proto, Paul J. 2005, The Significance of High Flow Events in the Lamprey River Basin, New Hampshire, for Annual Elemental Export and Understanding Hydrologic Pathways. M.S. Dissertation, Department of Earth Sciences, College of Engineering and Physical Sciences, University of New Hampshire, Durham, NH, 176 pages.
3. Buyofsky, Lauren A. May 2006. Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, MS Dissertation, Department of Natural Resources, College of Life Sciences and Agriculture , University of New Hampshire, Durham, NH, .
4. Legere, K.A. September 2007. Nitrogen loading in coastal watersheds of New Hampshire: an application of the SPARROW model. Masters Thesis, University of New Hampshire, Durham, NH. 75 pages.
5. Traer, K. December 2007. Controls on denitrification in a northeastern coastal suburban riparian zone. Masters Thesis, University of New Hampshire, Durham, NH. 97 pages.
6. Buyofsky, Lauren A., 2006, Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, "MS Dissertation", Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 176 pages.
7. Daley, M.L., J.D. Potter, W.H. McDowell. 2009. Salinization of urbanizing New Hampshire streams and groundwater: Impacts of road salt and hydrologic variability. Journal of the North American Benthological Society, submitted.
8. Buyofsky, Lauren A., 2006, Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, "MS Dissertation", Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 176 pages.
9. Daley, M.L., J.D. Potter and W.H. McDowell. 2009. Salinization of urbanizing New Hampshire streams and groundwater: impacts of road salt and hydrologic variability. Journal of the North American Benthological Society 28(4):929-940.

10. DiFranco, E. 2009. Spatial and temporal trends of dissolved nitrous oxide in the Lamprey River watershed and controls on the end-products of denitrification. M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 108 pages.
11. Daley, M.L. and W.H. McDowell. In Preparation. Nitrogen saturation in highly retentive coastal urbanizing watersheds. Ecosystems.
12. Daley, M.L. 2009. Nitrogen Sources and Retention within the Lamprey River Watershed and Implications for Management. State of the Estuaries Conference. Somersworth, NH. October 2009.
13. Daley, M.L. 2009. Water Quality of Private Wells in Suburban NH and Impacts of Land Use. Northeast Private Well Symposium. Portland, ME. November, 2009.
14. Daley, M.L. 2009. Spatial and Temporal variability in nitrogen concentrations, export and retention in the Lamprey River watershed. Joint NH Water and Watershed Conference. Concord, NH. November, 2009.
15. Daley, M.L. and W.H. McDowell. 2009. Nitrogen Saturation in Highly Retentive Watersheds? American Geophysical Union Fall Conference, San Francisco, CA. December, 2009.
16. Buyofsky, Lauren A., 2006, Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, "MS Dissertation", Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 176 pages.
17. Daley, M.L., J.D. Potter and W.H. McDowell, 2010, Nitrogen Assessment for the Lamprey River Watershed, Report prepared for the New Hampshire Department of Environmental Services. [http://des.nh.gov/organization/divisions/water/wmb/coastal/documents/unh\\_nitrogenassessment.pdf](http://des.nh.gov/organization/divisions/water/wmb/coastal/documents/unh_nitrogenassessment.pdf)
18. Dunlap, K, 2010, Seasonal Nitrate Dynamics in an Agriculturally Influenced NH Headwater Stream, M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 102 pages.
19. Galvin, M, 2010, Hydrologic and nutrient dynamics in an agriculturally influenced New England floodplain, M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 94 pages.
20. Daley, M.L., W.H. McDowell, B. Sive, and R. Talbot, In Preparation, Factors controlling atmospheric deposition at a coastal suburban site, Journal of Geophysical Research (Atmospheres).
21. Daley, M.L. and W.H. McDowell, 2010, Landscape controls on dissolved nutrients, organic matter and major ions in a suburbanizing watershed, American Geophysical Union Fall Conference, San Francisco, CA, December, 2010.
22. Davis, J.M., W.H. McDowell, J.E. Campbell and A.N. Hristov, 2010, Hydrological and biogeochemical investigation of an agricultural watershed, southeast New Hampshire, USA, American Geophysical Union Fall Conference, San Francisco, CA, December, 2010.
23. Hope, A.J. 2010. Ecosystem Processes in a Piped Stream. Plum Island Ecosystems Long Term Ecological Research All Scientists Meeting, Woods Hole, MA. April 8, 2010.
24. Hope, A.J. and W.H. McDowell, 2010, Ecosystem Processes in a Piped Stream, Aquatic Sciences: Global Changes from Center to Edge, ASLO & NABS Joint Summer Meeting, Santa Fe, NM, June 2010.
25. Buyofsky, Lauren A., 2006, Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, "MS Dissertation", Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 176 pages.
26. McDowell, W.H., M.L. Daley and J.D. Potter, 2011, Dissolved organic matter dynamics in a suburban basin: wetlands and people drive quantity and quality, North American Benthological Society Meeting, Providence, RI, May 2011.
27. McDowell, W.H. and M.L. Daley, 2011, Net Manageable Nitrogen: Definition and Rationale for a new approach to nitrogen management in moderately impacted watersheds, American Geophysical Union Fall Conference, San Francisco, CA, December, 2011.
28. McDowell, W.H. and M.L. Daley, 2011, Net Manageable Nitrogen: Definition and Rationale for a new approach to nitrogen management in moderately impacted watersheds, National Academy Keck

- Futures Initiative Ecosystem Services Conference, Irvine, CA, November, 2011.
29. Daley, M.L. and W.H. McDowell, In Preparation, Nitrogen saturation in highly retentive coastal urbanizing watersheds, Ecological Applications.
  30. Baillio, J., 2012, Controls on variability of dissolved greenhouse gas concentration and emissions from small streams in southeastern New Hampshire, MS Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 111 pages.
  31. Daley, M.L. and W.H. McDowell, In Preparation, Human impacts on stream nitrogen chemistry and watershed N retention across a wide range of rural to urban catchments, Ecological Applications.
  32. Liptzin, D., M.L. Daley, and W.H. McDowell. Accepted. A comparison of wet deposition collectors at a coastal rural site. Submitted to Water, Air, & Soil Pollution. April 2013.
  33. Parham, L., 2012, Spatial and temporal variation in degradation of dissolved organic carbon on the main stem of the Lamprey River, MS Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 66 pages.
  34. Hope, A.J., W.H. McDowell, W.M. Wollheim, Submitted, Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream, Biogeochemistry.
  35. Buyofsky, Lauren A., 2006, Relationships between groundwater quality and landscape characteristics in the Lamprey River watershed, "MS Dissertation", Department of Natural Resources, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 176 pages.
  36. Hope, A.J., W.H. McDowell, W.M. Wollheim. 2013. Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream. Biogeochemistry. September 2013. DOI 10.1007/s10533-013-9900-y
  37. Liptzin, D., M.L. Daley, and W.H. McDowell. 2013. A comparison of wet deposition collectors at a coastal rural site. Water, Air, & Soil Pollution. 224(5):1558. 2013.

# **Water Quality and the Landscape: Long-term monitoring of rapidly developing suburban watersheds**

## **Statement of Critical Regional or State Water Problem**

New Hampshire's surface waters are a very valuable resource, contributing to the state's economic base through recreation (fishing, boating, and swimming), tourism and real estate values, and drinking water supplies. New Hampshire is experiencing rapid growth in several counties and from 1990 to 2004 the state grew twice as fast as the rest of New England, with a state-wide average population increase of 17.2% during that period (Society for Protection of NH Forests 2005). New Hampshire watersheds rank among the most highly threatened watersheds in the nation because of the high potential for conversion of private forests to residential development. In fact, three of the four most threatened watersheds in the US which could experience the largest change in water quality as a result of increased residential development in private forests occur at least partially in New Hampshire (Stein et al. 2009).

The long-term impacts of this rapid population growth and the associated changes in land use on New Hampshire's surface waters are uncertain. Of particular concern are the impacts of non-point sources of pollution such as septic systems, urban runoff, stormwater, application of road salt and fertilizers, deforestation, and wetland conversion. Long-term datasets that include seasonal and year-to-year variability in precipitation, weather patterns and other factors are needed to adequately document the cumulative effects of land use change and quantify the effectiveness of watershed management programs. No other agency or research program (e.g. NH Department of Environmental Services (NH DES), US Geological Survey (USGS) or Environmental Protection Agency (EPA)) has implemented such a long-term program.

## **Statement of Results or Benefits**

The proposed project will provide detailed, high-quality, long-term datasets which will allow for a better understanding of the impacts of land use change and development on surface water quality. These surface water datasets could support the development, testing and refinement of predictive models, accurately assess the impacts of watershed management practices on drinking water supplies, assess efforts to reduce surface water quality impairments, and be potential early warning signs of dramatic changes to surface water quality in the region resulting from rapid development. Long-term datasets from this project will be essential to adaptive management strategies that strive to reduce non-point sources of nitrogen pollution in New Hampshire's Great Bay watershed which is currently impaired by elevated nitrogen and in violation of the Federal Clean Water Act. A list of selected recent presentations, publications and press releases that utilize long-term datasets supported by NH WRRC funding for this project is included at the end of this proposal.

## Objectives of the Project

This project allows for the continued collection of long-term water quality data in New Hampshire. It will use University of New Hampshire (UNH) staff, students and volunteers from local communities to collect samples from the Lamprey and Oyster River watersheds located in southeast NH and the Ossipee River watershed in central NH. All three watersheds are located in counties experiencing high population growth rates (Figure 1). Both the Lamprey and Ossipee watersheds are predicted to more than double in population from 1998 to 2020 (Sundquist and Stevens 1999). Surface water sites within each of the 3 watersheds and details on long-term datasets collected are described below. Together these 3 watersheds capture a broad range of urban, rural and agricultural land uses as well as a range of forests and wetland cover types.

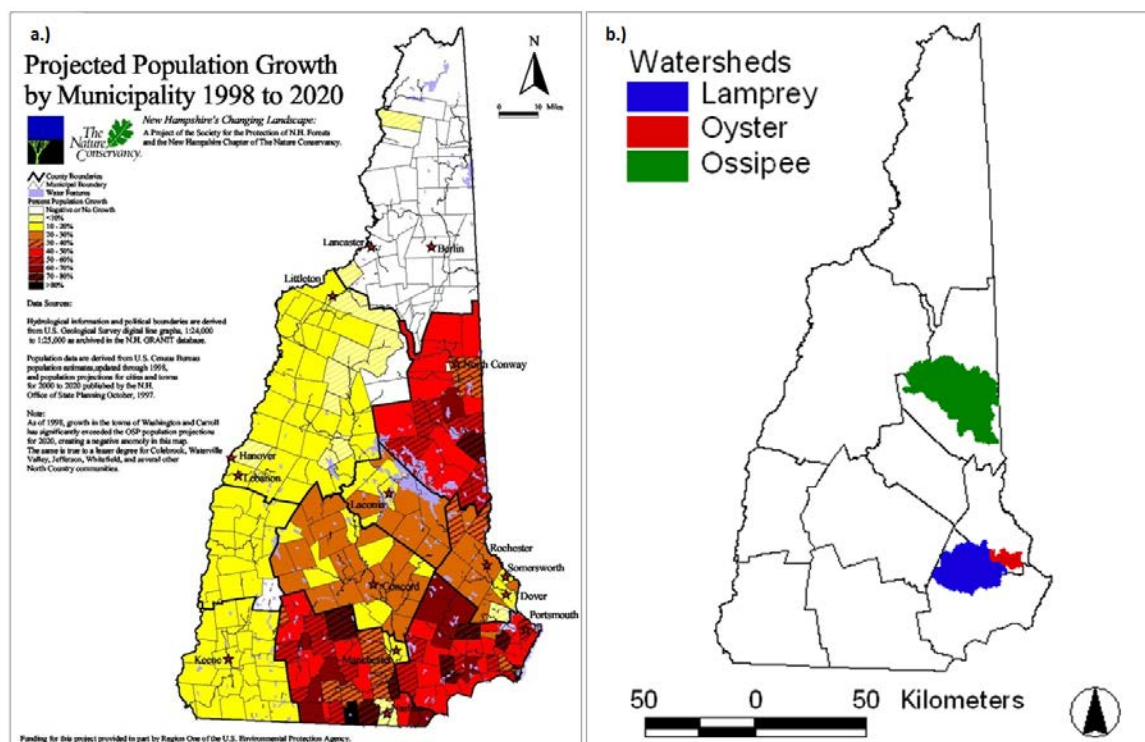


Figure 1. Projected population growth in New Hampshire (Figure from Sundquist and Stevens 1999; A) and study watersheds experiencing high population growth (B).

## Methods, Procedures and Facilities

### *Lamprey River Hydrologic Observatory*

The Lamprey River watershed (479 km<sup>2</sup>) is a rural watershed located in southeastern NH and is under large development pressure as the greater area experiences the highest population growth in the state. The Lamprey River Hydrologic Observatory (LRHO) is a name given to the entire Lamprey River basin as it serves as a platform to study the hydrology and biogeochemistry of a suburban basin and is used by the UNH community as a focal point for student and faculty research, teaching and outreach. Our goal for the long-term Lamprey water quality monitoring program is to document

changes in water quality as the Lamprey watershed becomes increasingly more developed and to understand the controls on N transformations and losses.

The Lamprey River has been sampled weekly and during major runoff events since September 1999 at site LMP73 which is co-located with the Lamprey River USGS gauging station (01073500) in Durham, NH. Two additional sites were added to the long-term Lamprey River monitoring program in January 2004. One site (NOR27) was located on the North River, the Lamprey River's largest tributary, less than 1 km downstream from the USGS gauging station (01073460) in Epping, NH. The other site (Wednesday Hill Brook; site WHB01) drains a small suburban area in Lee, NH where residents rely solely on private wells and private septic systems for water supply and waste disposal. A stream gauge at WHB01 is operated by UNH staff and/or students. Sites NOR27 and WHB01 were sampled on a weekly basis through 2010 and in January 2011, the North River sampling frequency (site NOR27) was reduced to monthly because accurate measures of river discharge were no longer possible. Site WHB01 along with LMP73 remain at a weekly and major storm event sampling frequency. Several other sites have been sampled for multiple years on a less frequent basis to assess the spatial variability of water quality in sub-basins with various land uses and development intensities. In the past year, 15 additional sites were sampled on a monthly basis. All LRHO stream water samples are collected by UNH staff and/or students.

### ***Oyster River watershed***

The Oyster River watershed (80 km<sup>2</sup>) is a small watershed in southeast NH where land use ranges from rural to urban. Two urban sub-basins, College Brook (CB) and Pettee Brook (PB), were selected for long-term sampling in January 2004. Both sub-basins are dominated by the University of New Hampshire (UNH) and receive a variety of non-point pollution from several different land uses. Three sites (CB00.5, CB01.5 and CB03.0) are sampled along College Brook which drains the center of campus and one site (PB02.0) is located on Pettee Brook which drains the northern section of campus. Both sub-basins drain areas with high amounts of impervious surface and College Brook also drains the UNH dairy farm and athletic fields. Historic water quality data for these two sites are available from 1991. UNH staff and/or students currently sample these sites on a monthly basis.

### ***Ossipee River watershed***

The entire Ossipee River watershed (952 km<sup>2</sup>) is classified as rural due to its low but increasing population. Seven sites in the watershed were selected for long-term monitoring in May of 2004. These sites are monitored monthly by volunteers and staff of the Green Mountain Conservation Group (GMCG) and were chosen to capture the areas of concentrated growth and monitor the major inputs and outputs from Ossipee Lake. Additional sites are selected by GMCG for volunteer monitoring during non-winter months (May to November). WRRRC staff assist GMCG in site selection and data interpretation. In 2006, the GMCG worked with the Department of Environmental Services to establish a Volunteer Biological Assessment Program (VBAP) for the Ossipee Watershed. Numerous volunteers, including students from five local schools, assist with invertebrate sampling at a total of eleven sites.

### ***Water Quality Analysis***

Field parameters (pH, conductivity, dissolved oxygen (DO) and temperature) are measured at all sites. Water samples are filtered in the field using pre-combusted glass fiber filters (0.7  $\mu\text{m}$  pore size), and frozen until analysis of dissolved constituents. Samples collected at all LRHO, CB, PB and the 7 long-term GMCG sites are analyzed for dissolved organic carbon (DOC), total dissolved nitrogen (TDN), nitrate ( $\text{NO}_3\text{-N}$ ), ammonium ( $\text{NH}_4\text{-N}$ ), dissolved organic nitrogen (DON), orthophosphate ( $\text{PO}_4\text{-P}$ ), chloride ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4\text{-S}$ ), sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), magnesium ( $\text{Mg}^{+2}$ ), calcium ( $\text{Ca}^{+2}$ ), and silica ( $\text{SiO}_2$ ). Water chemistry is also analyzed on a sub-set of the GMCG seasonal sites and turbidity is also measured in the field at all GMCG sites. Samples collected since October 2002 from LMP73 are also analyzed for total suspended sediment (TSS), particulate carbon (PC), particulate nitrogen (PN) and dissolved inorganic carbon (DIC). All samples are analyzed in the Water Quality Analysis Laboratory (WQAL) of the NH WRRC on the campus of UNH, Durham, NH. Methods for analyses include ion chromatography ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{+2}$  and  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{+2}$ ,  $\text{Ca}^{+2}$ ), discrete colorimetric analysis ( $\text{NH}_4$ ,  $\text{PO}_4$ ,  $\text{NO}_3/\text{NO}_2$ ), and High Temperature Oxidation (DOC, TDN). All methods are widely accepted techniques for analysis of each analyte.

The WQAL was established by the Department of Natural Resources in 1996 to meet the needs of various research and teaching projects both on and off the UNH campus. It is currently administered by the NH Water Resources Research Center and housed in James Hall. Dr. William McDowell has served as the Laboratory Director and Mr. Jody Potter is the Laboratory Manager. Together, they have over 40 years of experience in water quality analysis, and have numerous publications in the fields of water quality, biogeochemistry, and aquatic ecology.

### **Principal Findings and Significance**

#### ***Lamprey River Hydrologic Observatory***

Analysis of samples collected from the LRHO has been completed through 2013 and we are in the process of updating the LRHO website (<http://www.wrrc.unh.edu/lamprey-river-hydrologic-observatory>). Results of stream chemistry to date show a significant increase in nitrate concentrations during the first 10 years (Water Years (WY) 2000-2009) of monitoring at LMP73 and a slight decrease in nitrate concentrations in recent years (Figure 2). There was no significant change in nitrate concentrations at NOR27 or WHB01 over the last 10 years (2004-2013). We have shown previously that stream water nitrate is related to watershed population density (Daley 2002) and since suburbanization continues to occur throughout the greater Lamprey River watershed, population growth is likely responsible for the increase in stream water nitrate over the 10-year period. The watershed population density increased from 53 to 60 people/ $\text{km}^2$  or by 12% from 2000 to 2010 (2000 and 2010 Census). We are unsure if the lower nitrate levels measured in LMP73 during 2010 to 2013 will persist, increase or decrease with changing climate, land use and management in the watershed. Wednesday Hill Brook watershed is near its development capacity, unless the Town of Lee, NH changes its zoning regulations, and the lack of increase in WHB01 nitrate may be due to the limited population growth in this watershed, that this watershed has reached nitrogen saturation or that the current time period of data collection is not reflective of

long-term trends. Changes in Lamprey River nitrogen, especially nitrate, can have significant impacts for the downstream receiving water body, the Great Bay estuarine system which is impaired by elevated nitrogen and is currently in violation of the Federal Clean Water Act. Tidal tributaries to the bay are experiencing dangerously low dissolved oxygen levels and the bay is experiencing a significant loss of eelgrass which provides important habitat for aquatic life. The Lamprey River is the largest tributary to Great Bay, and thus the long-term data provided by the NH WRRC from the LRHO are of considerable interest for watershed management.

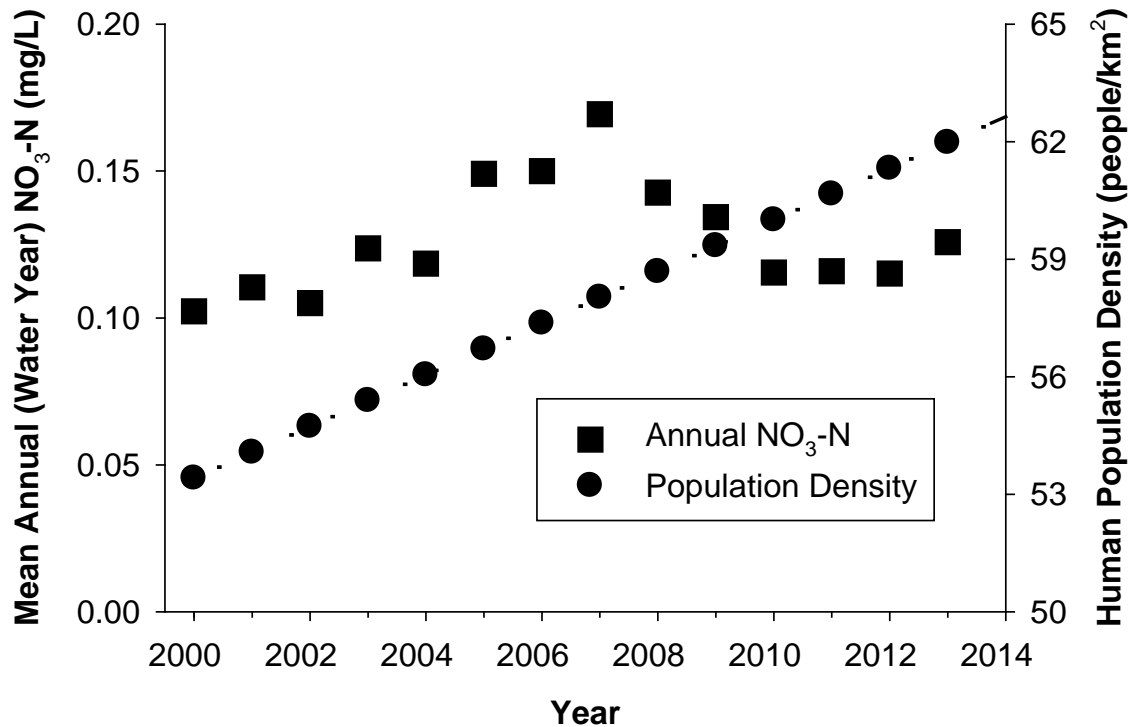


Figure 2. Annual (water year) nitrate concentration and estimated annual human population density from 2000-2013 (2000 and 2010 Census) in the Lamprey River basin. We have applied the Seasonal-Kendall Test (SKT; seasons set to 52) to weekly data from September 1999 through September 2009 and flow-adjusted nitrate concentrations have increased significantly over this time period (SKT  $t = 0.28$ ,  $p < 0.01$ ).

When we combine our specific conductance data (2002 – 2013) with data collected by the USGS (1978 - 1999), we see a long-term increase in specific conductance in the Lamprey River (Figure 3). Sodium and chloride concentrations are directly related to specific conductance ( $r^2 = 0.95$ ,  $p < 0.01$  for  $\text{Na}^+$ ;  $r^2 = 0.93$ ,  $p < 0.01$  for  $\text{Cl}^-$ ) and we conclude that this increase in specific conductance indicates a corresponding increase in  $\text{NaCl}$ . Since  $\text{Na}^+$  and  $\text{Cl}^-$  are strongly correlated with impervious surfaces in southeast NH (Daley et al. 2009) and road pavement among southeastern and central NH basins, we conclude that the associated road salt application to these surfaces is responsible for this temporal change in streamwater  $\text{NaCl}$ .

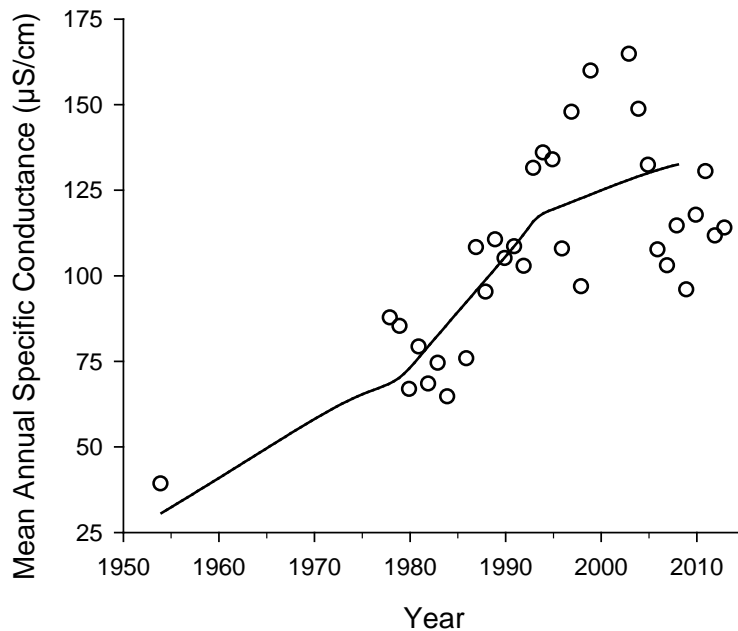


Figure 3. Mean annual specific conductance in the Lamprey River at LMP73 (co-located with the USGS gauging station in Durham, NH. (modified from Daley et al. 2009).

### ***Oyster River watershed***

Laboratory analysis of the monthly CB and PB samples is completed through 2013. Recent data show that DO is lowest at the CB upstream station (CB00.5) where it does drop below 5 mg/L (level that is necessary to support in-stream biota) during the summer months. The downstream stations do not drop below 5 mg/L and this difference is due to the hydrologic and biogeochemical properties of the upstream sampling location which has slow stream flow, high dissolved organic matter content and resembles a wetland. DO increases downstream as flow becomes faster and the stream is re-aerated. It is highly unlikely that historical incinerator operations are impacting present day DO levels in this brook as they have in the past.

Data from 2000 until now indicate that the stream is strongly impacted by road salt application at its origin, which is essentially a road-side ditch along the state highway leading to a wetland area, and by road salt applied by UNH and the town of Durham which drains to the middle and lower reaches of the brook. Average sodium and chloride concentrations, as well as specific conductance, appear to have remained reasonably constant since 2001, but are much higher than in 1991 (Daley et al. 2009). Concentrations are highest at the upstream stations and tend to decline downstream as the stream flows through the campus athletic fields and then increase as the stream passes through the heart of campus and downtown Durham. Concentrations are also highest during years of low flow. Data from this project have been used to list College Brook as impaired for excess chloride.

College Brook and Pettee Brook have noticeably higher nitrogen concentrations than many other local streams draining less developed or undeveloped watersheds. As College Brook flows from upstream to downstream where it becomes more aerated, ammonium decreases and nitrate increases (Figure 4) indicating that nitrification is occurring in the stream channel. However, an increase in total dissolved nitrogen (Figure

5) indicates that there are additional sources of nitrogen entering the stream as it flows downstream though UNH and Durham. This is possibly from fertilization of the athletic fields, storm water runoff or exfiltration from sewage lines. There is no statistically significant change in nitrate or TDN concentrations from 2000 to 2013 at the station with the longest record (CB01.5).

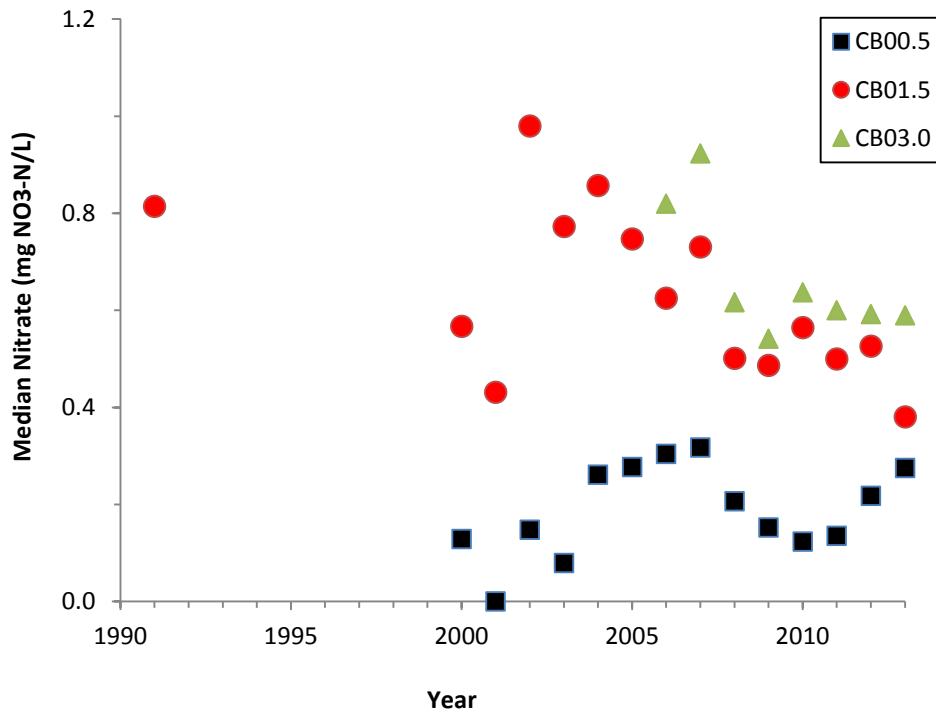


Figure 4. Median annual dissolved inorganic nitrogen (DIN) in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

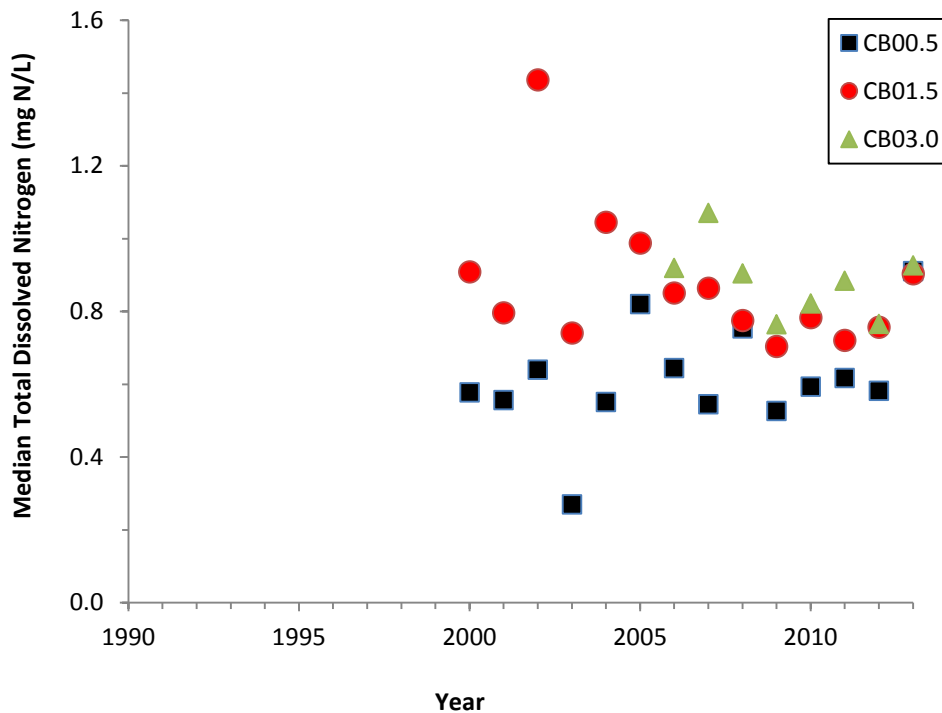


Figure 5. Median annual total dissolved nitrogen (TDN) in College Brook from the headwaters (CB00.5) to the mouth (CB03.0).

### ***Ossipee Watershed***

Collaboration with the Green Mountain Conservation Group (GMCG) and their sampling of the Ossipee River watershed provides much benefit to the NH WRRC and the long-term monitoring of rapidly developing suburban watersheds. Volunteers sampled streams within the watershed every 2 weeks from April through October, and monthly winter sampling was conducted by volunteers and GMCG staff at 7 sites. Over 100 samples were collected for analysis in the WQAL and additional field data was collected at over 40 sites throughout 6 towns using the help of many volunteers. Many presentations were made to planning boards, conservation commissions and other local government groups (see information transfer section below). Data have been used to heighten awareness of the impacts of excessive road salting and snow dumping in local streams. The impact of road salting in this central NH watershed is similar to what we see in coastal NH. Communication with local road agents has led to the remediation in one development where road salting was an issue. Samples collected and data generated from this funding have shown an improvement in water chemistry following reduced salting and snow dumping. Data have also been useful in promoting low impact development techniques and best management practices where new development has been proposed in proximity to lakes, rivers and streams within the watershed.

### **Notable awards and achievements**

N/A

## **Number of students supported**

Three Master's students (Bianca Rodriguez, Nicholas Shonka and Marleigh Sullivan), 5 undergraduate hourly employees from the Department of Natural Resources & the Environment (Matthew Bosiak, Katie Swan, Shannen Miller, Sarah Tierney and Jessica Pierce) and 1 undergraduate hourly employee from the Engineering Department (Thomas Brigham).

## **References**

Daley, M.L. May 2002. Export of Dissolved Organic Carbon, Dissolved Organic Nitrogen and Nitrate from the Lamprey River Watershed, New Hampshire: Examining Relationships with Watershed Characteristics. Master's Thesis, University of New Hampshire, Durham, NH.

Daley, M.L., J.D. Potter and W.H. McDowell. 2009. Salinization of urbanizing New Hampshire streams and groundwater: impacts of road salt and hydrologic variability. *Journal of the North American Benthological Society* 28(4):929–940.

Society for Protection of NH Forests. 2005. New Hampshire's Changing landscape. Population growth and land use changes: What they mean for the Granite State. (Available at: <http://www.spnhf.org/research/papers/nhcl2005es.pdf>).

Stein, S.M., McRoberts, R.E., Mahal, L.G., Carr, M.A., Alig, R.J., Comas, S.J., Theobald, D.M. and Cundiff, A. 2009. Private forests, public benefits: increased housing density and other pressures on private forest contributions. Gen. Tech. Rep. PNW-GTR-795. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

Sundquist D and Stevens M. 1999. New Hampshire's changing landscape. Population growth, land use conservation, and resource fragmentation in the Granite State. Society for the Protection of New Hampshire Forests, Concord, New Hampshire. 110 pp.

## **Information transfer activities that utilize long-term datasets supported by NH WRRC and matching funds**

### **Publications**

Daley, M.L. and W.H. McDowell. In Preparation. Human impact on N chemistry in streams visible at lowest population density in a range of suburbanizing basins. In Preparation for Ecological Applications.

Hope, A.J., W.H. McDowell, W.M. Wollheim. 2013. Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream. *Biogeochemistry*. September 2013. DOI 10.1007/s10533-013-9900-y

Liptzin, D., M.L. Daley, and W.H. McDowell. 2013. A comparison of wet deposition collectors at a coastal rural site. *Water, Air, & Soil Pollution*. 224(5):1558. 2013.

### **Conference Proceedings & Abstracts:**

Daley, M.L. and McDowell, W.H. 2013. Non-Point Nitrogen Sources and Transport Pathways in the Great Bay Watershed. NH Water and Watershed Conference. Plymouth, NH. March 2013.

Koenig, L. E.; Baumann, A. J.; McDowell, W. H. 2013. Improving automated phosphate analysis to eliminate silicate interference. (Abstract ID: 8116). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013

McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? European Geophysical Union Annual Meeting, Vienna, Austria April 2013 (invited keynote presentation).

McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? University of Amsterdam, Amsterdam, Netherlands. April 2013.

McDowell, W. G.; Rosemond, A. D.; McDowell, W. H.; Byers, J. E. 2013. Impacts, dead or alive: Effects of mass mortality of an abundant invasive species on ecosystem function. (Abstract ID: 7715). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013.

McDowell, W.H. 2013. Linkages between organic matter and carbon levels in surface waters and soils. UNESCO IHE Ecohydrology. Delft, Netherlands. June 2013.

Price, A. J.; Wollheim, W. M.; Mulukutla, G.; and McDowell, W. H. 2013. Headwater catchment nitrogen flux and storm response among land use types through seasons. (Abstract ID: 8050). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013.

Smith, Thor E., McDowell, William H., Wollheim, Wilfred M., Daley, Michelle, Mulukutla, Gopal, Baumann, Adam J., Snyder, Lisle, and Price, Allison. 2013. Sampling the Lamprey River watershed across space and time; New data collection efforts toward understanding nitrogen sources. The Geological Society of America Northeastern Section - 48th Annual Meeting. Omni-Mount Washington Hotel, Bretton Woods, New Hampshire. March 2013. *Abstract accepted but not presented due to federal employee travel restrictions.*

### **Presentations/Information Transfer**

Cripps, M.L. and Daley, M.L. 2013. Ossipee watershed: ten years of water monitoring. Presentation to Green Mountain Conservation Group (GMCG) Research

- Committee, Watershed Management Plan Steering Committee, Water Quality Monitoring Volunteers and GMCG Board, Freedom Village, NH. May 15, 2013.
- Daley, M.L. and McDowell, W.H. 2013. Aquatic Sensor Networks, Ecosystem Function and Management. NH EPSCoR all hands meeting. Durham, NH. March 28, 2013.
- Daley, M.L. 2013. Water Quality: How do you know if it is good or bad? Kingston, NH High School presentation to 180 high school students (9 groups of 20, 20 min each). June 4, 2013.
- Daley, M.L. 2013. Non-point nitrogen research in the Lamprey and Great Bay watershed. Great Bay boat tour with the NH House of Representatives Resources, Recreation and Development Committee. June 15, 2013.
- Daley, M.L. 2013. Research on nitrogen in the Great Bay watershed: Learn how diffuse sources of nitrogen pollution travel from our communities to the Great Bay. Scheduled for Contemporary Coastal Issues sail on the Gundalow in Portsmouth, NH on August 28, 2013. but sail was cancelled last minute due to fog. Will reschedule.
- Daley, M.L. Nitrogen Sources and Transport Update. Nitrogen Sources Collaborative Advisory Board. Lee, NH. August 29, 2013.
- Daley, M.L. 2013. Water Quality Research in the Lamprey River Hydrologic Observatory. Presentation to University of New Hampshire undergraduate class: Studio Soils. October 25, 2013.
- Daley, M.L. 2013. Presentation on “What it’s like to be a scientist and how I became a water quality scientist” to 40 6-8<sup>th</sup> graders from Epping Middle School during their visit to the University of New Hampshire. November 15, 2013.
- Daley, M.L. 2013. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Durham-UNH Integrated Permit and Planning Technical Advisory Committee. Oct 29, 2013.
- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport project results to members (Allison Watts and Paul Stacey) of the Water Integration for Squamscott-Exeter (WISE) NERRS Science Collaborative project to aid the project team in designing a water quality monitoring program. January 17, 2014.
- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Laura Byergo and Peter Wellenberger from Great Bay Stewards to discuss how this project might inform site locations chosen for the Great Bay Stewards “soak up the rain” effort. Jan 31, 2014

- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Mark Zankel and Peter Steckler from The Nature Conservancy (TNC) to discuss how the project can inform the next version of the TNC Land Conservation Plan for New Hampshire's Coastal Watershed. February 26, 2014.
- Kobylinski, A. 2013. Gave tour of Thompson Farm AIRMAP facility and demonstrated precipitation collection form a wet-only collector on top of an 80 foot tower to 10 senior environmental chemistry students from Phillip's Exeter Academy. Durham, NH. April 16, 2013.
- Koenig, L. 2013. Led 27 Dover High School students on a field trip to assess water quality in an urban stream draining the University of New Hampshire and to tour the UNH Water Quality Analysis Laboratory. May 30, 2013.
- McDowell, W.H. and M.L. Daley. 2013. Nonpoint nitrogen sources and transport in New Hampshire's Great Bay watershed. Presented at Nitrogen in Stormwater: Sources and Solutions Workshop, NH DES, Portsmouth, NH May 2013.
- May 16, 2013 Shared Great Bay N stormwater presentation with Carl Delo from EPA
- Swan, K. 2013. Spoke to students from the Stream Safari program at McLaughlin Middle School in Manchester, NH on "Why I became a scientist, what I do each day for work and how scientists monitor stream quality". November 13, 2013.
- Wollheim, W.W., A. Price, R. Careyu, G. Mulukutla, and W.H. McDowell. 2013. Storm event nutrient monitoring in river networks. Presented at Nitrogen in Stormwater: Sources and Solutions Workshop, NH DES, Portsmouth, NH May 2013.

## **Press Releases**

- Daley, M.L. 2013. Clean water: It's everyone's responsibility to reduce pollution and properly manage New Hampshire's land areas to protect our water resources. Blog June 18, 2013. <http://ecosystemsandsociety.blogspot.com/2013/06/clean-water-its-everyones.html>
- Forester Courtland, V. 2013. Upstream Impact: Graduate Students Inspire the Next Generation of STEM Scholars. UNH Today. May 30, 2013. [http://www.unh.edu/unhtoday/2013/05/upstream-impact?utm\\_source=Team+Update%3A+Ecosystems+and+Society+05%2F31%2F2013&utm\\_campaign=Team+Update&utm\\_medium=email](http://www.unh.edu/unhtoday/2013/05/upstream-impact?utm_source=Team+Update%3A+Ecosystems+and+Society+05%2F31%2F2013&utm_campaign=Team+Update&utm_medium=email). Koenig, L. featured in article.
- Gillies, J. 2014. New Hampshire stream monitoring network tracks Great Bay nutrient loading. Environmental Monitor. January 16, 2014. <http://www.fondriest.com/news/great-bay-new-hampshire-stream-monitoring.htm>. McDowell, W.H. interviewed for article.

- Morrill, D. 2013. Dogs who really know their business: Trained to find human waste in waterways. Foster's. Aug 2, 2013.  
[http://www.fosters.com/apps/pbcs.dll/article?AID=/20130802/GJNEWS\\_01/130809822](http://www.fosters.com/apps/pbcs.dll/article?AID=/20130802/GJNEWS_01/130809822). Daley, M.L. included in article.
- Nilsen, E. 2013. New Hampshire Pubic Radio "Statewide Project Looks At Ecosystems and Climate Change." August 21, 2013. <http://nhpr.org/post/statewide-project-looks-ecosystems-and-climate-change>. Snyder, L. interviewed for article.
- Potter, J.D., Godbois, A., Snyder, L. 2013. Cutting edge environmental monitoring comes to New Hampshire. Blog July 17, 2013.  
<http://ecosystemsandsociety.blogspot.com/2013/07/cutting-edge-environmental-monitoring.html>.

### **Green Mountain Conservation Group meetings, workshops and presentations supported by matching funds**

#### **2013**

- March 23, 9:00am-Noon (field visit from 12:00-1:00pm). Gravel Road Maintenance workshop with Russ Lanoie. Freedom Town Hall, Elm St., Freedom, NH.
- March 28, 6:00-8:00pm. Black Bear Presentation. Ossipee Public Library, Main St., Ossipee, NH.
- April 6, 10:00am-2:00pm. Well Water testing - Tractor Supply Community Event, Ossipee, NH.
- April 13, 10:00am-12:30pm. Volunteer Water Quality Monitoring Training. GMCG Offices, 196 Huntress Bridge Road, Effingham, NH.
- April 24 - May 22, 7:00am. Guided morning bird walks hosted by the Tamworth Conservation Commission, Tamworth Town House, Tamworth, NH.
- May 23. Well-water testing in Madison. Bring a sample of your well water for a limited but informative analysis.
- June 15th Macroinvertebrate stream survey in Eaton.
- July 24 th Well Water testing at White Mountain Hypnosis Center, Madison, NH.
- July 25, 6:30-8:30 pm. Invasive Insects. GMCG Office, 196 Huntress Bridge Rd., Effingham, NH.
- July 30 & Wednesday July 31, 9:00-4:00 pm. Water Topics for Teachers: a water literacy training opportunity for teachers. The Community School, Tamworth, NH.
- August 3, 8:30 am-Noon Household Hazardous Waste Day. Ossipee Town Hall, Ossipee, NH.
- August 10:00 am-3:00 pm. Get Wild at Sumner Brook, Ossipee NH. GMCG will partner with the Ossipee Conservation Commission to celebrate the natural resources in the Watershed—and come “fish the trout pond.”
- August 21, 10:00 am-1:00 pm. Volunteer Biological Assessment Training (VBAP). The Community School, Tamworth, NH.
- August 22, 10:00am-1:00 pm. Well Water Screening. GMCG Office, 196 Huntress Bridge Rd., Effingham, NH.

September- four schools participate in volunteer Biological Assessment Program (VBAP)

September 13th Freedom Elementary Students help install rain garden at Camp Huckins

VBAP stream study with 4 schools September 2013

VBAP Community Presentation with 4 schools December 6th 2013

## **2014**

Trout in the Classroom- 4 schools raise Eastern Brook trout for release in approved streams

February 13 4-6 pm. Valentines for volunteers- Join us to learn more about volunteering at the Huntress House

# Arsenic chemical dynamics in NH groundwater reservoirs: Insights from temporal variability in multi-element signatures of statewide samples

## Basic Information

<b>Title:</b>	Arsenic chemical dynamics in NH groundwater reservoirs: Insights from temporal variability in multi-element signatures of statewide samples
<b>Project Number:</b>	2011NH141B
<b>Start Date:</b>	3/1/2011
<b>End Date:</b>	2/28/2014
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	1
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Geochemical Processes, Groundwater, Toxic Substances
<b>Descriptors:</b>	
<b>Principal Investigators:</b>	Julia G Bryce

## Publications

There are no publications.

***Year 3 Project Report: “Arsenic chemical dynamics in NH groundwater reservoirs: Insights from temporal variability in multi-element signatures of statewide samples.”***

*PI Julia G. Bryce, USGS Collaborator Joe Ayotte, UNH Staff Florencia Prado*

*Student participants: Ian Carlisle (BS Geology UNH 2015); John Clark (BA Earth Sciences Teaching, UNH 2012; M.Ed. 2013)*

**1. Problem and Objectives**

The purpose of this project is to measure the concentrations of arsenic, a key regulated contaminant, in public and private groundwater wells distributed across the state of New Hampshire. In the early part this project, we focused on developing the arsenic method for analysis via hydride generation-high resolution inductively coupled plasma mass spectrometry. We optimized our analytical protocol for “harvesting” arsenic out of water samples originally collected for a MTBE study, and we optimized a set of procedures for investigating “leachable” arsenic from samples of local bedrock. By the end of the project

**2. Methods and Project Activities**

Our work is focused on developing analytical protocols to measure arsenic contents in existing samples. Nearly 900 samples exist from sampling campaigns led by J. Ayotte originally designed to study MTBE occurrences in groundwaters sampled from public and private drinking water supplies. Since some of the existing samples are older than recommended “hold” times for water samples, we first needed to ensure no arsenic has been lost from the system, via selective adsorption onto the bottle sides and/or via co-precipitation with other elements. Our approach to ensuring all arsenic is in solution was as follows. First we acidified the samples to 5% nitric acid, and then let sit for several days and shook and mixed via ultrasonic mixing. We then took a (quantified) cut for which we measured the arsenic concentration. We subsequently transferred the acidified solution to a cleaned bottle and filled the original bottle with 10% nitric, let sit, and then ran the results for arsenic concentration. We repeated this last bottle-leaching again with 15% nitric. Though we found that the 10% and 15% acidification steps were unnecessary in our pilot studies, since the solutions were stored for some time we have to consider the results we report minimum abundances of arsenic in the groundwater samples.

We have implemented the analysis of arsenic via hydride generator (Klaue and Blum, 1999) plumbed into a high resolution inductively coupled plasma mass spectrometer. Our detection limits were  $\sim < 0.02 \mu\text{g/kg}$ . We ran two blind standards provided by Joe Ayotte to run every 15-30 samples throughout each run day. We also used standard-sample-standard bracketing with NIST certified reference standard 1643e to correct for within-run drift and also ran standard curves using diluted natural water samples to assess matrix effects. Our lab has participated in the biannual USGS round robin since Fall 2012. In the most recent round robin period the recommended value

In another component of the study, we carried out leaching experiments with chipped bedrock samples to elucidate the geochemical controls on the contributions of arsenic from metasedimentary bedrock units. Our first analyses in support of these

investigations include the analysis of environmentally mobile arsenic in the Kittery formation. Our approach is adapted from that described in Peters and Blum (2003), wherein we used partial leaching in dilute acid to identify the readily mobilized As fractions. In addition to the acid leaching (carried out at  $\text{pH} \leq 1$ ), we carried out a subsequent study exposing the samples to solutions of elevated pH to test for the role of pH-selective absorption onto minerals on As mobilization (e.g., Peters and Blum, 2003 and references therein).

### **3. Findings**

In our assessments of accuracy and precision we ran a standard (NIST SRM 1643e, Trace elements in water) and found excellent accuracy and reproducibility. We have also participated in the USGS Round Robin measurements for standards every six months during this study. Following procedures we have developed, we reported our assessment of the standard, which came in below the median value reported for the unknown standard we were assigned. Though it is difficult to address the meaningfulness of the “median” value as it includes several different types of analytical approaches (some of which would not be used validly for samples with As of low abundance), we are continuing to run the standard using other techniques (e.g., standard addition) to ensure that we are accurately measuring sample values. Any offset in our values likely comes from a mismatch between the matrix of the standard we are using and the matrix of unknowns. Accordingly we will be carried out investigations of the influence of several different “matrix”-modifiers to ensure that our analytical protocols are not impacted by the high abundance of certain elements (e.g., Fe). We found negligible effects, and that we could correct for effects with standard-sample-standard bracketing techniques.

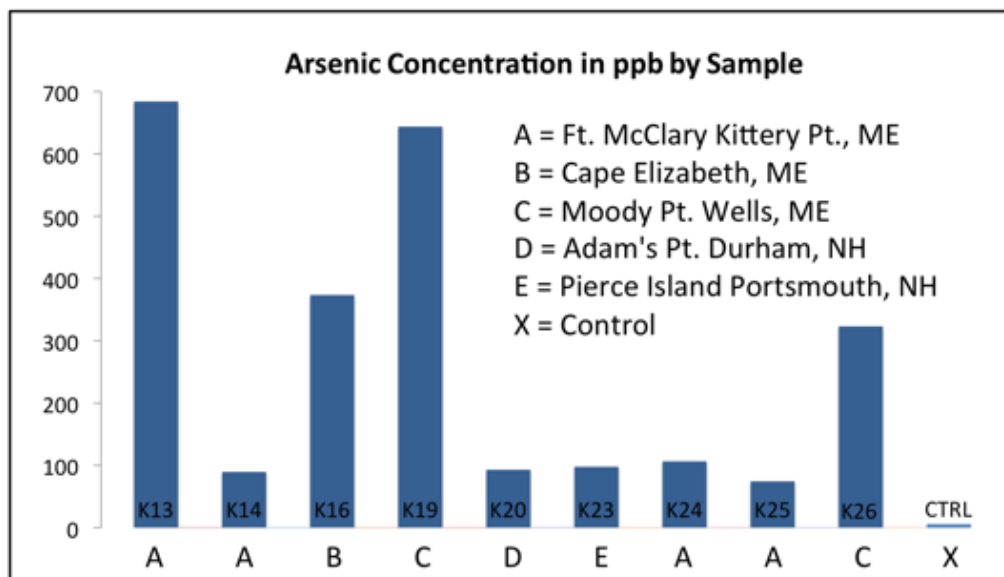
In terms of ensuring that we have no sample biasing issues with the shelf life of our samples, we spent the time on a subset of our samples to ensure we can establish a protocol for future measurements of the remainder of the 900 groundwater samples. Analyses of five samples showed, in cases where the original sample is above the detection limit, that we have a > 99% yield for the total arsenic in the system during the acidification to 5% nitric. Accordingly we will adopt these protocols with the rest of the unknown samples.

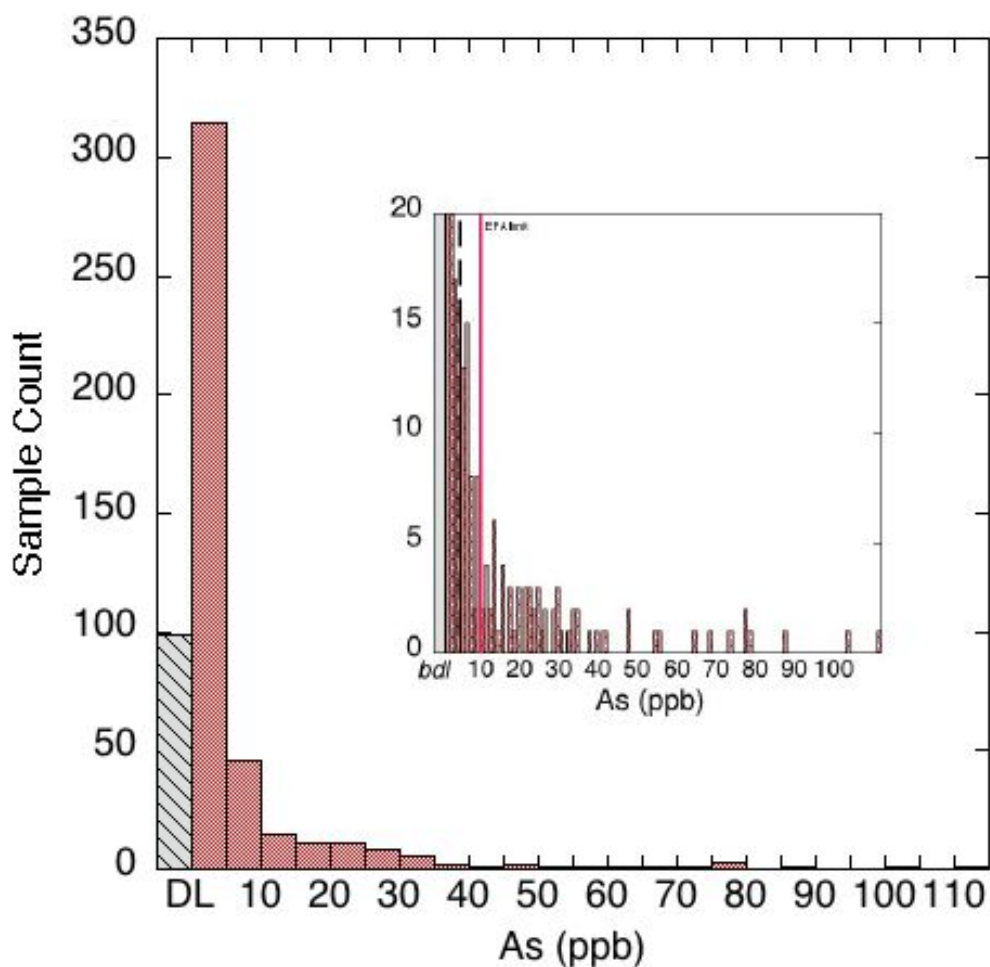
Our investigations of the environmentally mobile arsenic confirm the extreme range in arsenic that we can find over relatively short spatial scales in metasedimentary bedrock (Figure 1), as well as the strong sensitivity of subsequent arsenic remobilization due to changing pH in oxidizing conditions. We will complement our existing results on the Kittery with leaching studies of additional sub-samples from two existing ~100-foot six-inch drill cores through the Kittery and Elliot formations around the Great Bay in Southeastern NH and potentially from other bedrock units that host samples we have collected in the southern NH region.

The concentrations of arsenic in groundwater from the private and public water supplies measured thus far have been highly variable, with many samples exceeding the EPA-recommended drinking water limit (Figure 2). Two samples exceeded 100 ppb in concentration (Figure 2), well above recommended limits. Of the samples studied, 87% fall

below the EPA recommended limit for drinking water (10 ppb), and 79% fall below the 5 ppb mark, which is often suggested as a more appropriate recommended maximum contaminant level for drinking water. Disturbingly there are nearly 70 samples that exceed the EPA recommended drinking water limit, with 11 that bear As concentrations greater than 50 ppb (Figure 2).

*Figure 1. Arsenic concentrations in bedrock-leaching solutions from the Kittery formation. Note the extreme variability in the arsenic that is potentially environmentally mobile from different localities in the Kittery formation medasedimentary bedrock as well as the variability within individual localities..*





*Figure 2. As concentrations in NH groundwaters. DL refers to the 0.2 ppb detection limit we have established in our lab. Inset allows for the discernment of the relative abundance of samples exceeding recommended drinking water limits.*

#### **4. Presentation**

Results of the bedrock-leaching were presented at the 2012 UNH Undergraduate research project by Mr. John Clark (UNH BA-Earth Sciences Teaching, 2012). Clark started his activities on the project in summer 2011 and continued during the 2011-2012 and 2012-2013 academic years.

Results of a time-series project carried out by Mr. Ian Carlisle (UNH BS Geology, 2014) for his capstone research project found ~10% variations in As content in a well over a short sampling time that may link with groundwater recharge associated with storm events. Given the low number of such targeted studies, we recommend future studies should target temporal changes in As abundance.

We are working together with our USGS colleagues to analyze the data in a geospatial framework and plan to prepare a publication of the results shortly thereafter.

## **5.     *Outreach efforts***

Clark has finished his professional degree to be a secondary school science teacher, and his involvement in this project has provided him the opportunity to participate in “genuine” scientific research he can model with his future middle school students. He originally participated in this project as part of a summer research internship provided by a National Science Foundation grant for which Bryce is a co-PI. His attraction to the project came because of his belief that this was a project involving chemistry, public health and the environmental sciences, in such a way that he could engage his future students. His continued involvement during the academic year is a testimony to his long-standing interest.

In the spring 2013, we featured the results of this project in a hands-on lab day for a cadre of high school chemistry and Earth Science teachers separately supported by a Dreyfus Foundation Grant. The teachers were involved in sample collection, ICP analyses, and discussion of USGS studies of As in NH groundwaters, and are working with PI Bryce and Ms. Prado to establish As in groundwater as a unit in their chemistry and Earth Science classrooms.

## **6.     *Personnel development- students, faculty and staff***

In addition to Mr. Clark and Mr. Carlisle, whose analytical and student research efforts were supported by this project, this project is responsible for convincing Ms. Florencia Prado, a talented staff member to enter the Ph.D. program. Prado has developed the analytical techniques and worked with Bryce to supervise and develop the student projects.

# Award--Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.

## Basic Information

<b>Title:</b>	Award--Determining the Effectiveness of the Clean Air Act and Amendments for the Recovery of Surface Waters in the Northeastern U.S.
<b>Project Number:</b>	2011NH164S
<b>Start Date:</b>	3/28/2011
<b>End Date:</b>	4/30/2014
<b>Funding Source:</b>	Supplemental
<b>Congressional District:</b>	
<b>Research Category:</b>	Climate and Hydrologic Processes
<b>Focus Category:</b>	Acid Deposition, Surface Water, Law, Institutions, and Policy
<b>Descriptors:</b>	
<b>Principal Investigators:</b>	William H. McDowell, Steve Kahl

## Publications

1. Sanclements, M., G. Oelsner, D. McKnight, S.J. Nelson, J. Stoddard, 2012, New insights into the source of decadal increases of dissolved organic matter (DOM) in acid-sensitive lakes, Environmental Science and Technology, in press.
2. Nelson, S.J., P. Vaux, M.J. James-Pirri, and G. Giese, 2011, Assessment of natural resource conditions in and adjacent to Cape Cod National Seashore, Massachusetts, Natural Resource [Technical] Report NPS/XXXX/ NRXX—20XX/XXX, National Park Service, Fort Collins, Colorado, In press.
3. Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J.L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley, H. Yao, 2011, The effects of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA, Biogeochemistry DOI 10.1007/s10533-011-9664-1.
4. Sanclements, M., G. Oelsner, D. McKnight, S.J. Nelson, J. Stoddard, 2012, New insights into the source of decadal increases of dissolved organic matter (DOM) in acid-sensitive lakes of the northeastern U.S., Environmental Science and Technology, 46(6): 3212–3219, DOI: 10.1007/s11356-009-0176-7.
5. Nelson, S.J., P. Vaux, M.J. James-Pirri, and G. Giese, 2012, Natural resource condition assessment: Cape Cod National Seashore, Massachusetts, Natural Resource Report NPS/NER/NRR—2012/605, National Park Service, Fort Collins, Colorado.
6. Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J.L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley, H. Yao, 2011, The effects of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA, 111(1-3): 393-409, Biogeochemistry, DOI 10.1007/s10533-011-9664-1.

7. James-Pirri, M. J., S. J. Nelson, and P. D. Vaux, June 2011, Natural Resource Condition Assessment for Saugus Iron Works National Historic Site. Natural Resource Report NPS/NER/NRR—2011/457, National Park Service, Fort Collins, Colorado.
8. Sanclements, M., G. Oelsner, D. McKnight, S.J. Nelson, J. Stoddard, 2012, New insights into the source of decadal increases of dissolved organic matter (DOM) in acid-sensitive lakes of the northeastern U.S., *Environmental Science and Technology*, 46(6): 3212–3219, DOI: 10.1007/s11356-009-0176-7.
9. Nelson, S.J., P. Vaux, M.J. James-Pirri, and G. Giese, 2012, Natural resource condition assessment: Cape Cod National Seashore, Massachusetts, Natural Resource Report NPS/NER/NRR—2012/605, National Park Service, Fort Collins, Colorado.
10. Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J.L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley, H. Yao, 2011, The effects of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA, 111(1-3): 393-409, *Biogeochemistry*, DOI 10.1007/s10533-011-9664-1.
11. James-Pirri, M. J., S. J. Nelson, and P. D. Vaux, June 2011, Natural Resource Condition Assessment for Saugus Iron Works National Historic Site. Natural Resource Report NPS/NER/NRR—2011/457, National Park Service, Fort Collins, Colorado.
12. Strock, K., S. Nelson, J. Kahl, J. Saros, W. McDowell, 2014. Decadal trends reveal recent acceleration in the rate of recovery from acidification in the northeastern US. *Environ. Sci. Technol.* 48(9):4681-4689.
13. Strock, K.E. 2013. Deciphering Climate-Mediated Changes in Boreal Lake Ecosystems. Ph.D. Dissertation, University of Maine, Orono, Maine.
14. Boeff, K. 2014. Evaluating the effect of a changing climate on thermocline depth in Maine's Great Ponds. Master's thesis, University of Maine, Orono, Maine.

## Annual Report to

USGS WRD WRRI, Reston, VA  
US EPA, CAMD, Washington DC  
and US EPA, ORD, Corvallis OR

June, 2014

### ***Determining the effectiveness of the Clean Air Act and Amendments on the recovery of surface waters in the northeastern US***

IAG 06HQGR0143

Principal Investigators: William H. McDowell<sup>1</sup>, Sarah J. Nelson<sup>2</sup>, J. Steve Kahl<sup>1</sup>, J. Saros<sup>2</sup>  
<sup>1</sup>Univ. of New Hampshire, <sup>2</sup>Univ. of Maine

**Overview of activities during 2013-2014.** A schematic summary of progress on the project plan is provided below (Table 1) and discussed on the following pages. We have concluded the third year of five for the most current project agreement, which supports the continuing needs of EPA to assess the effectiveness of the Clean Air Act Amendments of 1990 (CAAA). Field work and data assessment continue on schedule. Project coordination as well as most analytical chemistry, and some field sampling are conducted by the University of New Hampshire. Additional field sampling, data quality assurance, and data reporting are conducted by the University of Maine. This year the project is partially funding a Postdoctoral Researcher who is evaluating recent trends in greenhouse gases in the LTM and TIME lakes and their relationship with water chemistry. Three graduate students at the University of Maine were partly funded through this project, or in research leveraged on this project. Kristin Strock completed a Ph.D. with Saros, Nelson et al. in fall 2013, and published one manuscript in Environmental Science and Technology based on the long-term data (Strock et al., 2014). Two M.S. students are working with PIs Saros and Nelson. M.S. student Kelsey Boeff successfully defended a thesis in Quaternary Studies dealing with changes in diatom community structure in LTM site Tunk Lake as well as other large lakes in Maine. M.S. student Rob Brown is completing a thesis that evaluates changes in lake thermal structure at three pairs of LTM lakes and a public water supply lake. Both M.S. students paired coring (proxy) measurements with contemporary chemical and physical data. Additionally, this project continues to fund a portion of the base program of stream chemistry monitoring at Bear Brook Watershed in Maine (BBWM), for the reference watershed, East Bear. BBWM is partway through a three-year NSF DEB grant that is evaluating nitrogen dynamics in both watersheds using <sup>15</sup>N tracer studies. The base funding through this IAG project created continuity that was key in securing the NSF award.

**Table 1.** 2011-2015 Project plan progress to date.

	2011				2012				2013				2014				2015				2016
<i>Project Activity</i>	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
project period																					
funding received																					
RLTM drainage																					
RLTM seepage																					
original LTM																					
HELM subset																					
BBWM - EB																					
TIME New England																					
TIME Adirondacks																					
sample analyses																					
Data submission																					
annual report																					

## Project background

Objectives. This research is part of EPA CAMD programs that are verifying the effectiveness of emission controls at reducing acidification of surface waters. Our approach is to collect long-term high-quality data that characterize the trends and patterns of response in low ionic-strength surface waters. We have specifically targeted waters that have been classified as being sensitive to acidic deposition and will represent lakes across the Northeast in varying landscape settings. The goals and methods are hierarchical, ranging from intensive site-specific investigations to regional assessment of sites that have been chosen to provide a statistically rigorous sample of regional surface waters. The objectives are to:

- 1) document the changes and patterns in aquatic chemistry for defined sub-populations and sites that are known to be susceptible to acidification or recovery;
- 2) evaluate the extent to which changes in surface waters, if any, can be linked to changes in deposition that are driven by regulatory actions;
- 3) characterize the effectiveness of the CAAA in meeting goals of reducing acidification of surface waters and improving biologically-relevant chemistry in the northeastern US;
- 4) provide information for assessment of the need for future reductions in atmospheric deposition based on the long-term trajectories of the systems under study; and
- 5) assess the extent to which increased variability in precipitation events will play a role in the long-term sustainability of CAAA success in these sensitive surface waters. This is leveraged through other funded research.

Approach. The schedule of tasks ranges from weekly to annual, continuing data records that now range from 17 to 30 years. We evaluate chemistry on a weekly basis year-round at the small watershed-scale at BBWM, quarterly in LTM, and annually during the historical index period for the TIME and HELM lakes. These project components provide a *statistical framework* for inferring regional patterns in chemistry using TIME and LTM (and ELS-II under separate funding). The *long-term records* of LTM, HELM and BBWM provide information on seasonal and annual variability, and thus provide a seasonal context for the annual surveys.

Expected Results. This information is needed for EPA to meet its Congressional mandate to assess the effectiveness of the CAAA. The combination of site-specific data within the regional context provides a rigorous assessment of the effects of declining pollutant emissions on SO<sub>4</sub> concentrations, base cation depletion, and changes in N-saturation or DOC contributions to acid-base status. The results are also central to assessing whether additional emission reductions may be needed to produce recovery.

## Project Status: Water Chemistry

**Field sampling.** All project field objectives in 2013 were accomplished as planned. A summary of the annual field schedule for this project is provided below (Table 2).

**Table 2.** Annual project field schedule for lake sampling

Project	sub-project	n	Times Sampled	Field work	May	June	July	Aug.	Sept.	Oct.
RLTM-Maine										
	seepage	3	3	UMaine	X		X			X
	drainage	10	3	UMaine/UNH	X		X			X
	LTM lakes	3	1	UMaine						X
TIME										
	New England	31	1	UNH			X	X	X	
	Adirondacks	43	1	ALSC			X	X	X	
HELM		25-30	1	UNH						X

**Analytical.** Analyses are complete for all samples collected through 2013. All laboratory analyses for TIME, RLTM, and HELM are conducted at the University of New Hampshire Water Quality Analysis Laboratory (WQAL) except for aluminum. Total and organic aluminum samples are processed on an ICP at the USDA Forest Service Region 1 laboratory in Durham, NH. All analyses for TIME, RLTM, and HELM continue to be conducted by, or under the supervision of, Jody Potter as has been the case since 2012.

Samples from East Bear Brook at BBWM, which are collected on a regular basis year-round, continue to be analyzed at the University of Maine Sawyer Environmental Chemistry Research Lab.

**Data reporting.** All data collected through 2012 have been delivered to EPA. The next delivery of data to EPA is expected before August 2014, after evaluation of inter-laboratory comparisons and regular QA analyses by UNH and UMaine.

**Presentation of findings.** Several publications and presentations continue to result from this project and are listed at the end of this report. Recent leveraged funding is supporting portions of two M.S. theses and a Ph.D. dissertation at UMaine under the supervision of co-PI Saros.

**New developments:** During the past two years we were able to make routine two new sets of analyses to continue to extract new and innovative information from these study sites. A subset of lakes were analyzed for DOC quality using SUVA and fluorescence (EEMS) analysis, as well as concentrations of the dissolved greenhouse gases (CH<sub>4</sub>, CO<sub>2</sub>, and N<sub>2</sub>O) in surface waters. Moving forward this data will provide valuable insight into changes in organic sources to acid-base status as well as the influence of precipitation event variability on long-term changes in surface water chemistry.

*Publications using related project information (recent publications in bold):*

**Strock, K., S. Nelson, J. Kahl, J. Saros, W. McDowell, 2014. Decadal trends reveal recent acceleration in the rate of recovery from acidification in the northeastern US. Environ. Sci. Technol. 48(9):4681-4689.**

- Sanclements, M., G. Oelsner, D. McKnight, S.J. Nelson, J. Stoddard, 2012. New insights into the source of decadal increases of dissolved organic matter (DOM) in acid-sensitive lakes of the northeastern U.S. *Environmental Science and Technology* 46(6): 3212–3219; DOI: 10.1007/s11356-009-0176-7.
- Nelson, S.J., P. Vaux, M.J. James-Pirri, and G. Giese. 2012. Natural resource condition assessment: Cape Cod National Seashore, Massachusetts. Natural Resource Report NPS/NER/NRR—2012/605. National Park Service, Fort Collins, Colorado.
- James-Pirri, M. J., S. J. Nelson, and P. D. Vaux. June 2011. Natural Resource Condition Assessment for Saugus Iron Works National Historic Site. Natural Resource Report NPS/NER/NRR—2011/457. National Park Service. Fort Collins, Colorado.
- Kerr, J.G., M.C. Eimers, I.F. Creed, M.B. Adams, F. Beall, D. Burns, J.L. Campbell, S.F. Christopher, T.A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D.S. Jeffries, G.E. Likens, M.J. Mitchell, J. Shanley, H. Yao, 2011, The effects of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA, *Biogeochemistry* DOI 10.1007/s10533-011-9664-1.
- Navrátil, T., S.A. Norton, I.J. Fernandez, S.J. Nelson, 2010. Twenty-year inter-annual trends and seasonal variations in precipitation and stream water chemistry at the Bear Brook Watershed in Maine, USA. *Environ. Monit. Assess.* 171:3-21.
- Norton, S.; Fernandez, I.; Kahl, J.; Rustad, L.; Navratil, Tomas; Almquist, H., 2010. The evolution of the science of Bear Brook Watershed in Maine, USA. *Environmental Monitoring and Assessment*, 171(1-4): 3-21.
- Vaux, P.D., S.J. Nelson, N. Rajakaruna, G. Mittelhauser, K. Bell, B. Kopp, J. Peckenham, G. Longworth, 2008. Assessment of natural resource conditions in and adjacent to Acadia National Park, Maine. Natural Resource Report NPS/NRPC/WRD/NRR—2008/069. National Park Service, Fort Collins, Colorado.
- Baumann, A.J. and J.S. Kahl, 2007. Chemical trends in Maine High Elevation Lakes. *LakeLine* 27:30-34.
- Hunt, K., J.S. Kahl, J. Rubin, and D. Mageean, 2007. Assessing the science-based needs of stakeholders; a case study on acid rain research and policy. *Journal of Contemporary Water Research and Education*, 136: 68-79.
- Rosfjord, C., K. Webster, J.S. Kahl, S.A. Norton, I. Fernandez, and A. Herlihy, 2007. Anthropogenically-driven changes in chloride complicate interpretation of base cation trends in lakes recovering from acidic deposition. *Environ Sci Technol*, 41:7688 -7693.
- Rosfjord, C., J.S. Kahl, K. Webster, S. Nelson, I. Fernandez, L. Rustad, and R. Stemberger 2006. Acidic deposition-relevant changes in lake chemistry in the EPA Eastern Lake Survey, 1984-2004. Final report to USDA NSRC, Durham, NH. 69 p.
- Campbell, J, J. Hornbeck, M. Mitchell, M. Adams, M. Castro, C. Driscoll, J.S. Kahl, and others, 2004. Input-output budgets for inorganic nitrogen for 24 watersheds in the northeastern United States. *Water Air Soil Pollut.*, 151:373-396.
- Lawler, J., J. Rubin, B.J. Cosby, I. Fernandez, J.S. Kahl, S. Norton, 2005. Predicting recovery from acidic deposition: Applying a modified TAF (Tracking Analysis Framework) Model to Maine High Elevation Lakes, *Water Air Soil Pollut.* 164:383-389.

- Dupont, J., T. Clair, C. Gagnon, D. Jeffries, J.S. Kahl, S. Nelson, and J. Peckenham, 2005. Estimation of critical loads of acidity in the northeastern US and eastern Canada. *Environ. Monit. Assess.* 109:275-291.
- Kahl, J.S., J. Stoddard, R. Haeuber, S. Paulsen, R. Birnbaum, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, K. Roy, W. Sharpe, S. Urquhart, R. Webb, and K. Webster, 2004. Response of surface water chemistry to changes in acidic deposition: implications for future amendments to Clean Air Act. *Environmental Science and Technology*, Feature Article 38:484A-490A.
- Norton, S., I. Fernandez, J.S. Kahl, and R. Reinhardt, 2004. Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed, Maine, USA. *Water, Air, Soil, Pollution Focus* 4:289-310.

*Dissertations/theses:*

- Strock, K.E. 2013. Deciphering Climate-Mediated Changes in Boreal Lake Ecosystems. Ph.D. Dissertation, University of Maine, Orono, Maine.**
- Boeff, K. 2014. Evaluating the effect of a changing climate on thermocline depth in Maine's Great Ponds. Master's thesis, University of Maine, Orono, Maine.**

*Presentations using related project information (recent presentations in bold) :*

- Appling, A.P., W.H. McDowell, J.D. Potter, S.J. Nelson, J.S. Kahl, 2014. From the frying pan into the fire? Lake greenhouse gas responses to acid rain recovery. Joint Aquatic Sciences Meeting. Portland, OR, May 18 – 23, 2014.**
- Brown, R.E., Saros, J.E. & S.J. Nelson. 2014. Algal community response to increases in dissolved organic carbon over recent decades. Poster presentation. Association for the Sciences of Limnology & Oceanography, Portland, OR, May, 2014.**
- Boeff, K. & J.E. Saros. 2014. Evaluating the effect of a changing climate on thermocline depth in Maine's Great Ponds. Poster presentation. Association for the Sciences of Limnology & Oceanography, Portland, OR, May, 2014.**
- Brown, R.E., Saros, J.E. & S.J. Nelson. 2014. Algal community response to increases in dissolved organic carbon over recent decades. Poster presentation. Maine Water Conference, Augusta, ME, March, 2014.**
- Strock, K.E., Saros, J.E., Nelson, S.J. & S. Birkel. 2014. Interactive effects of extreme weather and reduced sulfate deposition: accelerated recovery from acidification and increased brownification in lakes of the Northeast U.S. Association for the Sciences of Limnology & Oceanography, Portland, OR, May, 2014.**
- Boeff, K. & J.E. Saros. Evaluating the effect of changing wind strength on thermocline depth in Maine's Great Ponds. 22nd Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2014.**

**Brown, R.E., Saros, J.E. & S.J. Nelson. 2014. Algal community response to increases in dissolved organic carbon over recent decades. 22nd Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2014.**

**S.J. Nelson, 2013. School of Forest Resources Faculty Blitz. Sept. 13, 2013.**

**Boeff, K. & J.E. Saros. 2013. Evaluating the effect of a changing climate on thermocline depth in Maine's Great Ponds. Poster presentation. North American Diatom Symposium, Bar Harbor, ME, August, 2013.**

**Brown, R.E., Saros, J.E. & S.J. Nelson. 2013. Algal community response to increases in dissolved organic carbon: Implications for drinking water utilities. Poster presentation. North American Diatom Symposium, Bar Harbor, ME, August, 2013.**

Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, B. Zoellick, 2013. Validating landscape models for mercury in northeastern US lakes using dragonfly larvae as mercury bio-sentinels. Accepted for poster presentation at the ICMGP - International Conference on Mercury as a Global Pollutant, July 28- Aug. 3, 2013, Edinburgh, Scotland.

Boeff, K., J. Saros. 2013. Evaluating the Effect of Changing Wind Strength on Thermocline Depth in Maine's Great Ponds. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Brown, R.E., J.E. Saros, S.J. Nelson. Algal community response to increases in dissolved organic carbon in Maine lakes: implications for drinking water utilities. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Strock, K.E., J.E. Saros, S. Birkel, S.J. Nelson, 2013. Exploring the effects of extreme hydrologic events in the northeastern U.S.: Implications for brownification and episodic acidification in Maine Lakes. 21st Annual Harold W. Borns Jr. Symposium, Orono, ME, USA, April, 2013.

Nelson, S.J., C. Chen, D.P. Krabbenhoft, J.S. Kahl, 2013. Dragonfly larvae as mercury bio-sentinels: a statistical survey of northeast lakes reveals landscape-driven patterns in water and biota mercury concentrations. NERC (Northeastern Ecosystems Research Cooperative) meeting, March 19 – 20, 2013, Saratoga Springs, NY.

Strock, K.E.D., J.E. Saros, S.J. Nelson. 2013. The effects of extreme climate events on lakewater chemistry: Implications for "brownification" in Maine lakes. Maine Water Conference. Augusta, Maine, March 19, 2013.

Strock, K.E.D., J.E. Saros, S.J. Nelson, S.D. Birkel. 2013. The effects of extreme climate events on lakewater chemistry: implications for dissolved organic carbon trends in the northeast U.S. American Society of Limnology and Oceanography Meeting. New Orleans, Louisiana, February 17-22, 2013.

- Sanclements, M., G. Oelsner, D. McKnight, I.J. Fernandez, S.J. Nelson, M.B. Adams, M. Mineau, K. Simon, 2012. The effects of acidification and recovery on DOM quality and source in temperate forested watersheds. BIOGEOMON 2012, July 15-20, 2012, Northport, ME.
- Strock, K.E., J.E. Saros, S.J. Nelson, 2012. Analyzing Legacy Data in a Climate Context to Decipher Modern Changes in Lakewater Chemistry. Poster presentation. BIOGEOMON 2012, July 15-20, 2012, Northport, ME.
- Fernandez, I.J., Norton, S.A., Nelson, S.J., Salvino, C., 2012. Evidence of Transient Alteration of N Dynamics From an Ice Storm at the Bear Brook Watershed in Maine, USA. Poster presentation. BIOGEOMON 2012, July 15-20, 2012, Northport, ME.
- Saros, J.E., K.E.D. Strock, S. Birkel & S.J. Nelson. 2012. Deciphering the effects of extreme hydrologic events on the response of northeastern lakes to reduced sulfur deposition. 20th annual Harold W. Borns Symposium, University of Maine.
- Nelson, S.J., J.S. Kahl, A.J. Baumann, K.B. Johnson, 2012. “Rugged shores and clear waters”: Interpreting biogeochemical response to environmental stressors using the lakes and ponds of Maine’s Baxter State Park. Maine Water Conference, Augusta, ME, March 14, 2012.
- Strock, K.E., J.E. Saros, S. Nelson. Why climate matters in recovery from acidification in northeastern US surface waters. Maine Water Conference, Augusta, ME, March 14, 2012.
- Baumann, A.J., J.S. Kahl, T.R. Boucher, S.J. Nelson, and K.J. McGuire, 2012. “Changes in surface water chemistry in Maine high elevation lakes in response to the 1990 Clean Air Act Amendments. Maine Water Conference, Augusta, ME, March 14, 2012.
- Mineau, M. M., K. S. Simon, D. T. Ely; R. L. Rancatti, I. J. Fernandez, S. A. Norton, and H. M. Valett. 2011. Effects of chronic nitrogen enrichment and acidification on coupled nitrogen and phosphorus cycling in streams: Insights from multiple spiraling techniques. Annual meeting, North American Benthological Society, Providence, RI.
- Nelson, S.J., P. Vaux, M.J. James-Pirri. Data-driven assessments of National Park resources. (Invited). Acadian Internship in Regional Conservation and Stewardship, July 15, 2011.
- Schneider, S.B., I.J. Fernandez, S.A. Norton, K.S. Simon. 2011. Soil base cation response to two decades of change at the Bear Brook Watershed in Maine. Gordon Conference on Catchment Science: Interactions of Hydrology, Biology and Chemistry. Bates College, Lewiston, Maine. July 10-15.
- Nelson, S.J., C. Chen, H. Roebuck, B. Zoellick. Sensible sentinels: Preliminary mercury data for dragonfly nymphs (*Odonata: anisoptera*) across northern New England corroborate expected spatial pattern. The 10th International Conference on Mercury as a Global Pollutant (ICMGP), Halifax, NS, July 24-29, 2011; and presented at the Acadia Science Symposium, October 26, 2011.

- Baumann, A.J., and J.S. Kahl, 2009. Assessing the effectiveness of federal acid rain policy using remote and high elevation lakes in northern New England. North American Lake Management Society International Symposium, Hartford, CT, October 29, 2009.
- Kahl, J.S., 2009. Changes in base cations related to long-term changes in Cl distribution in northeastern lakes. Gordon Research Conference, Forested Catchments, July 12-17, 2009, Proctor Academy, NH.
- Kahl, J.S., 2008 (invited). Twenty year changes in spatial patterns of Cl distribution in the northeastern US. NH Water Conference, April, 2008.
- Kahl, J.S., 2007 (invited). Using societal-based incentives to address new threats to New England Lakes. Day-long short course in New England Lake Science Academy, Camp Kieve, Maine. July, 2007.
- Kahl, S., K. Webster, D. Sassan, C. Rosfjord, S. Nelson, M. Greenawalt-Yelle, 2007. Increasing Cl in northeastern surface waters: an indicator of increasing development pressure. Maine Water Conference, Augusta, ME, March 21, 2007.
- Kahl, J.S. 2006 (invited). Acid rain in New England: using high elevation lakes as sentinels of change. Maine Mountain Conference, October 21, 2006. Rangeley, Maine
- Kahl, J.S., *et al.*, 2006 (invited). The design of a national mercury monitoring network: Learning from the EPA acid rain experience. The Eighth International Mercury Conference, Madison WI, August 8, 2006.
- Kahl, J.S. *et al.*, 2006. Obfuscation of trends in base cations by regional salt contamination. Hubbard Brook Committee of Scientists annual meeting, July 12, 2006.
- Kahl, J.S., 2006 (invited). 'Natural and human-derived sources of acidity in Maine Atlantic Salmon Rivers'. Atlantic Salmon Commission workshop on acidity, Bangor ME. April 10, 2006.
- Kahl, J.S., 2005 (invited). The intersection of environmental science and environmental policy. NH Charitable Foundation Lakes Region annual meeting, Meredith, NH, September, 2005.
- Kahl, J.S., 2005 (invited). Tracking response and recovery in surface waters in the northeastern US. Annual meeting of the Ecological Society of America, Montreal, August, 2005.
- Kahl, J.S., and Catherine Rosfjord, 2005 (invited). Acid rain and the Clean Air Act in the northeastern US. Annual meeting of the NH-ME Androscoggin River Watershed Council, Bethel, June, 2005
- Kahl, J.S., 2005 (invited). Developing a lake research agenda for NH. NSF workshop on lake research infrastructure in the northeast, Colby Sawyer College, April 2005.
- Kahl, J.S., S. Nelson, and A. Grygo, 2004. Surface water chemistry data for the northeastern US for interpreting climate and acid rain trends. Northeast Ecosystems Research Consortium meeting, Durham, NH, October, 2004.
- Kahl, J.S., K. Webster, M. Diehl, and C. Rosfjord, 2004. Successes of the Clean Air Act Amendments of 1990. Maine Water Conference invited plenary talk, Augusta, ME, 2004.
- Kahl, J.S. and K. Johnson, 2004. Acid-Base Chemistry and Historical Trends in Downeast Salmon Rivers. Maine Water Conference, Augusta ME, April 2004.
- Kahl, J.S., 2004 (invited). The Clean Air Act Amendments of 1990; testing a program designed to evaluate environmental policy. Lecture, Colby College. April, 2004

- S.J. Nelson, J.S. Kahl, N.C. Kamman, D.P. Krabbenhoft, W.H. Halteman, 2009. (Poster)  
Predicting mercury concentrations in northeast lakes using hydrogeomorphic features,  
landscape setting and chemical co-variates. Gordon Research Conference, Forested  
Catchments, July 12-17, 2009, Proctor Academy, NH.
- Nelson, S.J., I. Fernandez, S. Norton, B. Wiersma, L. Rustad, J.S. Kahl, 2008. The Bear Brook  
Watershed in Maine: Long-term research supporting climate change inquiry. Hydroclimatic  
effects on ecosystem response: participant workshop, Syracuse, NY, September 19, 2008.
- Nelson, S.J., N. Kamman, D. Krabbenhoft, J.S. Kahl, K. Webster, 2008. Evaluating spatial  
patterns in mercury and methyl mercury in northeastern lakes: Landscape setting, chemical  
climate, and human influences. Northeastern Ecosystem Research Cooperative Conference,  
Durham, NH, November 12-13, 2008.
- Nelson, S.J. 2008. Evaluating spatial patterns in mercury and methyl mercury in northeastern  
lakes: landscape setting, chemical climate, and human influences. Maine Water Conference,  
Augusta, ME, March 19, 2008.

**Recent Bear Brook publications and presentations that include “base program” data (East Bear Brook stream chemistry partly funded through this grant):**

Mineau M. M., F. R. Fatemi, I. J. Fernandez and K. S. Simon. 2014. Microbial enzyme activity at the watershed scale: Response to chronic nitrogen deposition and acute phosphorous enrichment. *Biogeochemistry* 117:131-142.

Mineau, Madeleine M., Chad M. Grigsby, Damon T. Ely, Ivan J. Fernandez, Stephen A. Norton, Tsutomu Ohno, H. Maurice Valett, and Kevin S. Simon. 2013. Chronic catchment nitrogen enrichment and stoichiometric constraints on the bioavailability of dissolved organic matter from leaf leachate. *Freshwater Biology* 58:248-260.

Gruselle, Marie-Cecile, Cayce Salvino, Ivan J. Fernandez, Kevin Simon and Corianne Tartariw. 2013. Does Chronic N Fertilization Increase P Limitation in Northeastern U.S. Forest Soils? (Paper 383-4). Presented at the ASA-CSSA-SSSA International Meetings. Tampa, Florida. November 3-6. ASA, CSSA, SSSA, Madison, WI.

Fatemi, Farrah, Michael D. SanClements, and Ivan J. Fernandez. 2013. Microbial Carbon Cycling Along a Drainage Sequence in a New England Forested Watershed. (Paper 252-2). Presented at the ASA-CSSA-SSSA International Meetings. Tampa, Florida. November 3-6. ASA, CSSA, SSSA, Madison, WI.

Morse, Jennifer L., Jorge Duran, Fred Beall, Irena Creed, Eric Enanga, Ivan Fernandez, and Peter M. Groffman. 2013. Soil denitrification fluxes and oxygen dynamics in three contrasting northeastern North American forests. *Ecological Society of America*. Minneapolis, Minnesota 8/4-8/9.

SanClements, Michael, Ivan Fernandez, Mary Beth Adams, and Jenny Erwin. 2013. Linking Stream DOM Quality and Source to Watershed Acidification and Recovery in Temperate Forests of the Northeastern United States. 12th North American Forest Soils Conference, Whitefish, Montana. p. 112.

Gruselle, Marie-Cecile, Ivan Fernandez, and Corianne Tatariw. 2013. Manganese Dynamics in the Third Decade of Forest Ecosystem Experimental Acidification and Nitrogen Enrichment. 12th North American Forest Soils Conference, Whitefish, Montana. p. 35

MacRae, J.D., C. Tatariw, D. Rothenheber, S. Nelson, I.J. Fernandez. The effects of nitrogen enrichment on forest soil microbial communities and their activities, 2013 AEESP 50th Anniversary Conference, July 14-16, Golden, CO.

- Boca, Antra, Mercedes Roman Dobarco, Helga Van Miegroet, Marie-Cecile Gruselle, Beate Michalzik, and Ivan Fernandez. 2013. Linding Overstory, Soil and Climate Characteristics to Explain C Storage in Forest Soils. 12th North American Forest Soils Conference, Whitefish, Montana. p. 29.
- Gruselle, M.-C., Fernandez, I., Simon, K., Norton S., 2013. The effects of long-term ecosystem N enrichment on <sup>15</sup>N dynamics at the Bear Brook Watershed in Maine. NERC 2013 Conference, Saratoga Springs, NY.
- Minocha, Rakesh, Swathi A. Turlapati, Stephanie Long, Mohammad M. Bataineh, Aaron Weiskittel, Ivan Fernandez, and Lindsey Rustad. 2013. Chronic N and S additions impact foliar physiology of forest trees at the Bear Brook Watershed in Maine, USA. Hubbard Brook Experimental Forest Annual Meeting, Thornton, NH.
- Ohno, Tsutomu, Ivan J. Fernandez, Rachel L. Sleighter, and Patrick G. Hatcher. Influence of depth on soil organic matter characteristics: An ultrahigh resolution mass spectrometry study. Advanced Analytical Characterization of Natural Organic Matter, Goldschmidt 2013, Florence, Italy, August 25-30, 2013.
- Fernandez, Ivan J. and Sarah J. Nelson. 2013. Bear Brook, Backpack Sprayers, and What's More Fun Than Gym Class? Invited seminar at the School of Forest Resources noon-time seminar series. University of Maine, Orono, Maine.
- Mayewski, Paul, Ivan J. Fernandez, Stephen A. Norton and Sean Birkel. 2013. Presentation on Climate Change and Maine to the Allagash Wilderness Waterway Advisory Council. March 22. Augusta, Maine.
- Fatemi, Farrah R., Ivan J. Fernandez, Stephen A. Norton and Lindsey E. Rustad. 2013. Soil solution response to two decades of experimental acidification at the Bear Brook Watershed in Maine. *Water Air Soil Pollut.* 223:6171–6186.
- Mineau, Madeleine M., Chad M. Grigsby, Damon T. Ely, Ivan J. Fernandez, Stephen A. Norton, Tsutomu Ohno, H. Maurice Valett, and Kevin S. Simon. 2013. Chronic catchment nitrogen enrichment and stoichiometric constraints on the bioavailability of dissolved organic matter from leaf leachate. *Freshwater Biology* (in press).
- Fernandez, Ivan J., Stephen A. Norton, and Tiffany Wilson (eds.). 2012. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. 261 pp.

- Fernandez, Ivan J., Madeleine M. Mineau, Kevin S. Simon, and Stephen A. Norton. 2012. The influence of decadal-scale N enrichment on N dynamics and  $^{15}\text{N}$  discrimination in a New England Forested Watershed. (Paper 302-2). Presented at the ASA-CSSA-SSSA International Meetings. Cincinnati, Ohio. October 22-25. ASA, CSSA, SSSA, Madison, WI.
- Mineau, M.M., K.S. Simon, I.J. Fernandez, S.A. Norton, and H.M. Valett. The effect of chronic watershed nitrogen deposition and acidification on the interaction among phosphorus, carbon, and nitrogen uptake in streams. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 167.
- Norton, S.A., I.J. Fernandez, T. Navratil, K.S. Simon, and S. Jain. 2012. The Bear Brook Watershed in Maine (BBWM) at 25: manipulation, monitoring, mechanisms, and modeling. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 177.
- Rancatti, R., K. Simon, M. Mineau, D. Anderson, I.J. Fernandez, S.A. Norton, and M.B. Adams. 2012. Effects of watershed acidification on abiotic and biotic phosphorus uptake in streams draining two whole-watershed experimental forests. BIOGEOMON 2012, The 7th International Symposium on Ecosystem Behavior. Northport, Maine. ISBN 978-0-87723-108-0. p. 204.

# James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response

## Basic Information

<b>Title:</b>	James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response
<b>Project Number:</b>	2012NH168B
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<b>End Date:</b>	2/28/2014
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<b>Descriptors:</b>	
<b>Principal Investigators:</b>	Robert Roseen, Thomas P. Ballestero

## Publications

There are no publications.

# **James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response, Final Report, April 2014**

*Submitted to*

The New Hampshire Water Resources Research Center

May 16, 2014

*Submitted by*

The University of New Hampshire Stormwater Center

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## **Executive Summary**

The University of New Hampshire Stormwater Center (UNHSC) has completed a six month field verification study of a green roof system installed on James Hall at the University of New Hampshire in Durham NH. Monitoring took place from July 2013 through November 2013. A total of nine storms were evaluated and runoff from the vegetated roof system was compared to runoff from an equally sized section of untreated rooftop from which performance characteristics were developed.

The overall project objective was to evaluate performance with respect to effluent water quantity and water quality as compared to runoff from a reference roof section. Water quantity was monitored at the effluent of each roof section at 5-minute intervals throughout each sampled event. Laboratory analyses were conducted by the UNH Water Quality Analysis Laboratory (WQAL) within the Department of Natural Resources & the Environment. Water quality samples were processed for the following parameters: Nitrate/Nitrite in water (NO<sub>3</sub>, NO<sub>2</sub>), Total Dissolved Nitrogen (TDN), Ammonium (NH<sub>4</sub>), Total Nitrogen (TN), Total Phosphorus (TP), and Phosphate (PO<sub>4</sub>).

Results indicate that this vegetated roof section provides limited benefits with respect to water quantity and water quality control. The vegetated roof system appears best suited to reduce peak runoff flows from the rooftop by filtering water through the pervious reservoir. Peak flows exhibited an overall average reduction of 27%, however overall volume reductions were not observed. For water quality parameters the vegetated roof system exhibited export of Nitrogen and Phosphorus. Average concentrations of dissolved organic nitrogen and total phosphorus were an order of magnitude higher in the vegetated roof outlet compared to the flat roof reference, while average phosphate concentrations were two orders of magnitude higher in the vegetated roof outlet compared to the flat roof reference. The vegetated roof system did show a capacity to remove dissolved inorganic forms of nitrogen (DIN: NO<sub>3</sub>, NO<sub>2</sub>, and NH<sub>4</sub>) removing 59% of the measurable DIN the most common ionic (bioavailable) forms of nitrogen in aquatic ecosystems.

Most promising is the vegetative roof systems buffering of dissolved oxygen (DO) and pH levels in effluent runoff. Average effluent levels from the vegetated roof system were 1.6 and 0.8 points higher for DO and pH respectively. While water quantity and quality benefits are widely marketed as features of vegetated roof systems it is clear that attention to volume reduction and nutrient control are important elements of any discussion of vegetated green roof systems. Designs to enhance control of nutrients and volume retention should be carefully considered. Other elements of vegetated roof benefits not explored in this study such as carbon sequestration and energy efficiency may be ancillary benefits that trump water quantity and water quality concerns.

## **Site Description**

James Hall underwent renovations that were completed in 2010 to become the first LEED (Leadership in Energy and Environmental Design) Gold certified building on the University of New Hampshire Durham campus. One of the sustainable innovations incorporated into the design is a gray water system that collects rainwater from the building's roof for use in the toilets. One section of the roof was outfitted with a 400ft<sup>2</sup> modular vegetated roof system designed to capture and treat direct rainfall before draining into the gray water system. Adjacent to the vegetated roof section is an equally sized conventional rubber roof that serves as the comparative control for monitoring and research purposes. Both roof sections have independent roof drains leading into the gray water piping network within James Hall. This side-by-side design allows researchers to evaluate the water quality and hydrologic performance of the system.

The vegetated roof is comprised of 100 plastic modular trays that are 2ft square by 4in deep. The trays are filled with a mixture of chipped stone (3/8in chip shale) and loam, and planted with a variety of succulents. Many vegetated roof systems utilize succulents because they thrive in extreme arid climates through their ability to store water over long periods. Roof tops provide an ideal environment for these plants due to the inconsistency

of rainfall patterns and elevated temperatures. Under the trays is a non-woven geotextile fabric that protects the conventional rubber roof from plant roots and other protrusions that could potentially damage the underlying impermeable layer. The roof section is pitched to the center of the 20ft by 20ft square where a roof drain is located. An adjacent conventional flat roof has the exact same dimensions and layout in order to provide an apples-to-apples comparison.

## Project Overview

This research provides a greater understanding of the treatment capacity of vegetated roofs for nitrogen (N) and phosphorous (P) runoff from flat roof structures. These constituents play a major role in the health of our urbanized surface waters and understanding the removal efficiency of vegetated roofs in a cold climate setting plays an important role in the future of non-point source pollution control. Hydrographs for storm events, snow/ice melt and drain down periods were obtained to determine the hydrologic function of the vegetated roof. This hydrologic data ties in a water balance and a rainfall-runoff relationship to compare with the treatment efficiency of the vegetated roof.

Objective: The University of New Hampshire Stormwater Center (UNHSC) in collaboration with the Natural Resources Department faculty and staff examined the water quality and hydrologic performance of a conventional rubber roof and vegetated roof system.

## Water Quality Monitoring

### Sample Analysis

Analytical testing of water samples consisted of Nitrate + Nitrite, Ammonium, Total Dissolved Nitrogen, Total Nitrogen, Phosphate, and Total Phosphorus. Analytes and methods are listed in Table 1. Analytical and methods procedures are outlined in the UNHSC Quality Assurance Project Plan, which can be made available upon request.

**Table 1: Analytes and Analytical Methods**

<b>ANALYTE</b>	<b>METHOD</b>
Nitrate/Nitrite in water	EPA 353.2
Total Dissolved Nitrogen (TDN)	High temp oxidation w/ chemiluminescent detection
Ammonium	EPA 350.1
Total Nitrogen + Total Phosphorus	Resource Investigations Report 03-4174
Phosphate	EPA 365

### Methods and Sampling

Monitoring of roof runoff was facilitated through the use of existing drainage infrastructure within James Hall. Water quality samples and real-time hydrologic monitoring data were collected in order to evaluate the differences between the vegetated green roof and conventional rubber roof sections. Storm event monitoring was conducted through summer and fall of 2013 over a wide range of rainfall characteristics (i.e. rainfall depth, rainfall intensity, storm duration, and antecedent dry period) (see Table 2). Automated sampling and monitoring equipment was installed to sample from the roof drain systems independently. The samplers were programmed to sample 100 milliliter aliquots at flow-weighted intervals into 1 liter containers. The samplers have a 24 x 1 liter bottle capacity which allows for a maximum of 240 samples per event. The sampling program is designed

to ensure adequate coverage of the storm event and is adjusted to accommodate seasonal fluctuations in rainfall patterns. Rejection criteria included minimum rainfall depth of 0.1 inches, minimum of 10 aliquots per sampling event, and at least 70% coverage of the total storm volume.

After the storm event the data was collected and samples were transported to the UNHSC field facility for post-processing. The flow-weighted samples were composited into identical 1 liter samples which are further processed into two 60ml sub-samples. One 60ml sub-sample was filtered through glass microfiber filters with 1.0 $\mu$ m pore size and the other 60ml sub-sample is unfiltered. The samples are then frozen until delivery to the UNH Water Quality Analysis Laboratory (WQAL) within the Department of Natural Resources & the Environment.

## Equipment

Teledyne ISCO 6712 Portable samplers (Figure 1) were used to monitor hydrology and take water quality samples during storm events. Each sampler was outfitted with an ISCO 730 Bubbler module to continuously monitor water depth throughout each rain event. Using programmable features of the 6712 the monitored water depth was instantaneously computed into flow using Mannings' equation. Flow values are used to quantify runoff volumes which help to determine flow-weighted intervals. The samplers are equipped with twenty-four 1 liter sample bottles lined with disposable LDPE liners to ensure integrity of each sample. Rainfall was recorded using an ISCO 674 Rain Gauge located at the UNHSC field facility approximately 1 mile from the study site. The 1 liter composite samples are generated using a USGS Decaport Cone Splitter and sample splitting matrix developed by UNHSC research staff. Whatman Glass Microfiber Filters were used for processing the filtered s

**Figure 1: ISCO Portable Sampler with 6712 programmable control head.**



## Results

A total of 9 storm events were sampled between July and November of 2013. Table 2 lists the storm dates and respective storm hydrologic characteristics for each sampled event. Total storm depths ranged from 0.12 inches

to 2.98 inches and peak rainfall intensities ranged from 0.12 inches per hour to 2.16 inches per hour. This demonstrates a wide range of sampled events over the course of the study period. Peak flows from each roof drain are also listed to demonstrate the vegetated roof's capacity to reduce peak flows. All but one event showed a reduction in peak flow and the average peak flow reduction over the study period was 27%. There was no discernable difference in the total volume of runoff, nor was there any detectable effect of antecedent dry period. The second longest antecedent dry period (14 days) led to the largest negative discrepancy in runoff volume between the study and reference sites.

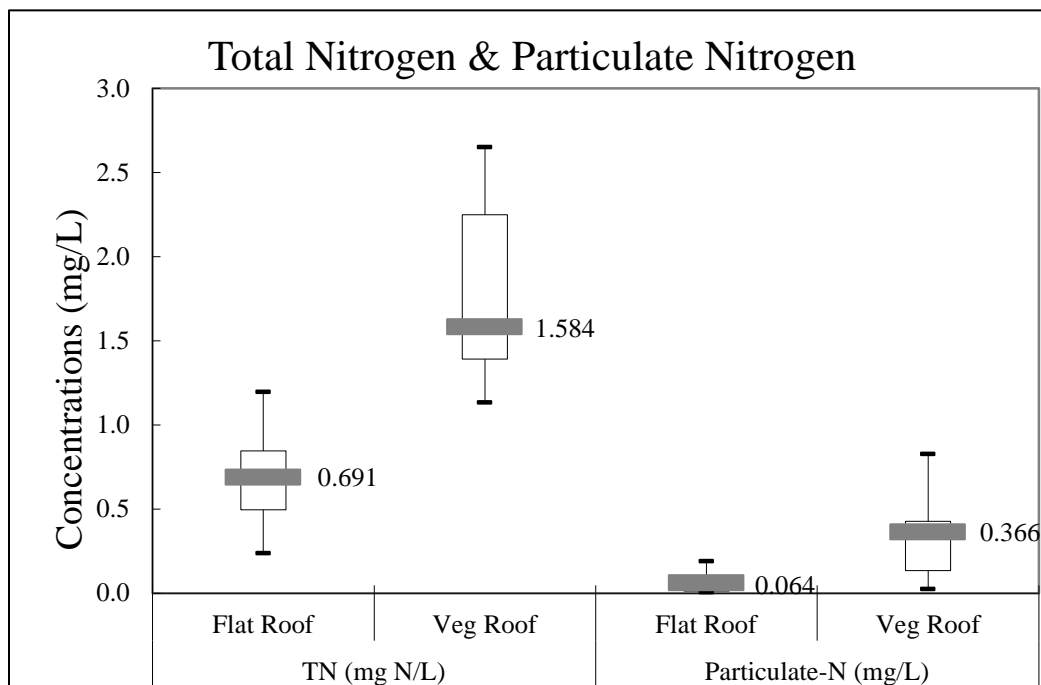
**Table 2: Summary table of storm event hydrologic characteristics for each monitored storm event.**

Date	Duration (min)	Total Rainfall (in)	Peak Intensity (in/hr)	Antecedent Dry Period (days)	Veg Roof Peak Flow (gpm)	Flat Roof Peak Flow (gpm)	Peak Flow Reduction %	Veg Roof Total Volume (gpm)	Flat Roof Total Volume (gpm)	Volume Reduction %
7/11/2013	1325	0.22	0.72	3	16.1	9.0	-79%	976	425	-130%
7/23/2013	1155	0.48	0.48	5	8.8	14.8	41%	959	1072	10%
8/1/2013	1095	0.53	0.48	7	5.2	9.7	46%	492	1069	54%
8/9/2013	4865	2.10	2.16	7	25.8	38.8	33%	1912	2381	20%
9/12/2013	2230	2.98	2.04	6	34.5	35.9	4%	2418	2349	-3%
9/22/2013	1440	0.60	1.68	9	26.1	34.8	25%	990	681	-45%
10/6/2013	1900	0.26	0.24	14	2.6	6.6	60%	1311	383	-242%
10/31/2013	1240	0.12	0.12	22	1.8	2.2	18%	546	373	-47%
11/17/2013	1370	0.27	0.48	7	1.0	10.5	91%	108	873	88%
MIN	1095	0.12	0.12	3	1.0	2.2	-79%	108	373	-242%
AVERAGE	1847	1	1	9	13.5	18.0	27%	1079	1067	-33%
MEDIAN	1370	0.48	0.48	7	8.8	10.5	33%	976	873	-3%
MAX	4865	2.98	2.16	22	34.5	38.8	91%	2418	2381	88%

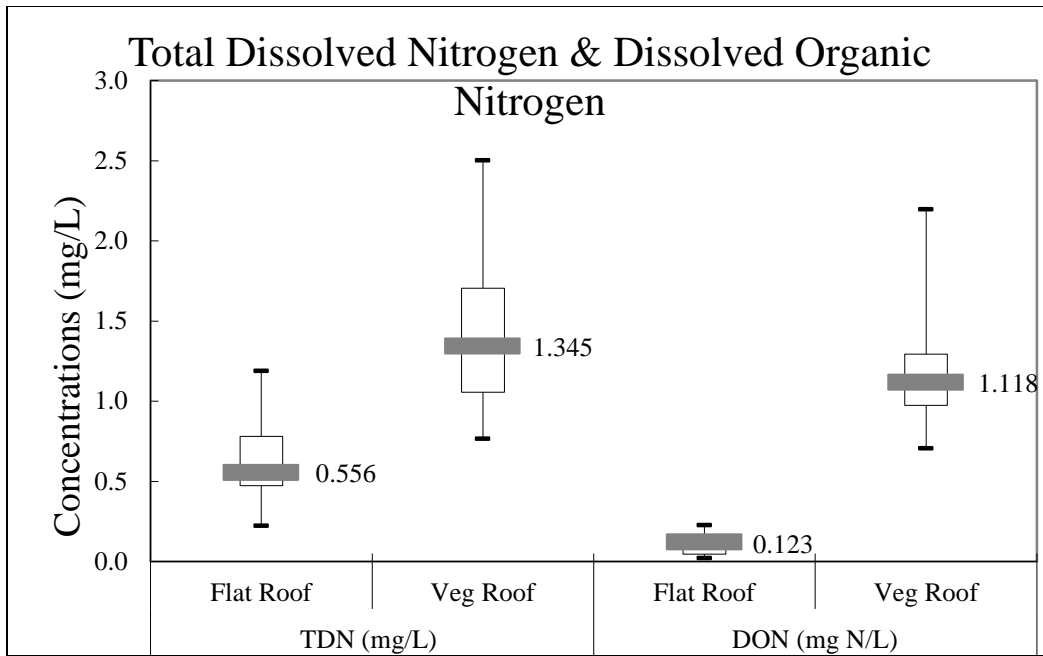
Results of water quality monitoring for the 9 storm events are listed in Table 3 and Table 4 and displayed in box and whisker plots in Figure 2 through Figure 5. The data shows that the vegetated roof system exported Total Nitrogen (TN), Particulate Nitrogen, Total Dissolved Nitrogen (TDN), and Dissolved Organic Nitrogen (DON) for all of the sampled rain events. The removal efficiency for each pollutant was -216%, -1,034%, -170%, and -1,983% respectively. The results are similar for Phosphate (PO<sub>4</sub>) and Total Phosphorus (TP) showing average removal efficiencies of -15,450% and -3,273% respectively. The vegetated roof system demonstrated positive removal efficiencies for DIN species with Nitrate (NO<sub>3</sub>) + Nitrite (NO<sub>2</sub>) exhibiting an average removal rate of 33% and Ammonium (NH<sub>4</sub>) performance exhibiting an average removal rate of 84%.

**Table 3: Water quality monitoring results for the conventional flat roof and vegetated green roof including total nitrogen (TN), particulate nitrogen, total dissolved nitrogen (TDN), and dissolved organic nitrogen (DON) concentrations.**

Date	TN (mg N/L)			Particulate-N (mg/L)			TDN (mg/L)			DON (mg N/L)		
	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%
7/11/2013	2.167	0.789	-175%	0.365	0.057	-540%	1.802	0.732	-146%	1.184	0.023	-5151%
7/23/2013	2.499	0.670	-273%	0.828	0.080	-932%	1.671	0.589	-184%	1.345	0.134	-904%
8/1/2013	2.652	0.503	-428%	0.150	0.006	-2360%	2.502	0.497	-404%	2.197	0.173	-1170%
8/9/2013	1.556	0.475	-227%	0.575	0.071	-706%	0.981	0.404	-143%	0.915	0.226	-305%
9/12/2013	1.134	0.713	-59%	0.367	0.190	-93%	0.766	0.522	-47%	0.705	0.053	-1231%
9/22/2013	1.459	0.238	-513%	0.377	0.014	-2561%	1.082	0.224	-384%	1.052	0.112	-840%
10/6/2013	1.189	1.014	-17%	0.026	0.088	71%	1.164	0.926	-26%	0.993	0.141	-605%
10/31/2013	1.612	1.196	-35%	0.085	0.007	-1148%	1.527	1.189	-28%	1.277	0.022	-5657%
MIN	1.134	0.238	-513%	0.026	0.006	-2561%	0.766	0.224	-404%	0.705	0.022	-5657%
25th Q	1.392	0.496	-312%	0.134	0.012	-1451%	1.057	0.473	-234%	0.974	0.045	-2211%
MEDIAN	1.584	0.691	-201%	0.366	0.064	-819%	1.345	0.556	-144%	1.118	0.123	-1037%
AVERAGE	1.783	0.700	-216%	0.347	0.064	-1034%	1.437	0.635	-170%	1.209	0.110	-1983%
75th Q	2.250	0.845	-53%	0.427	0.082	-428%	1.704	0.780	-42%	1.294	0.149	-781%
MAX	2.652	1.196	-17%	0.828	0.190	71%	2.502	1.189	-26%	2.197	0.226	-305%



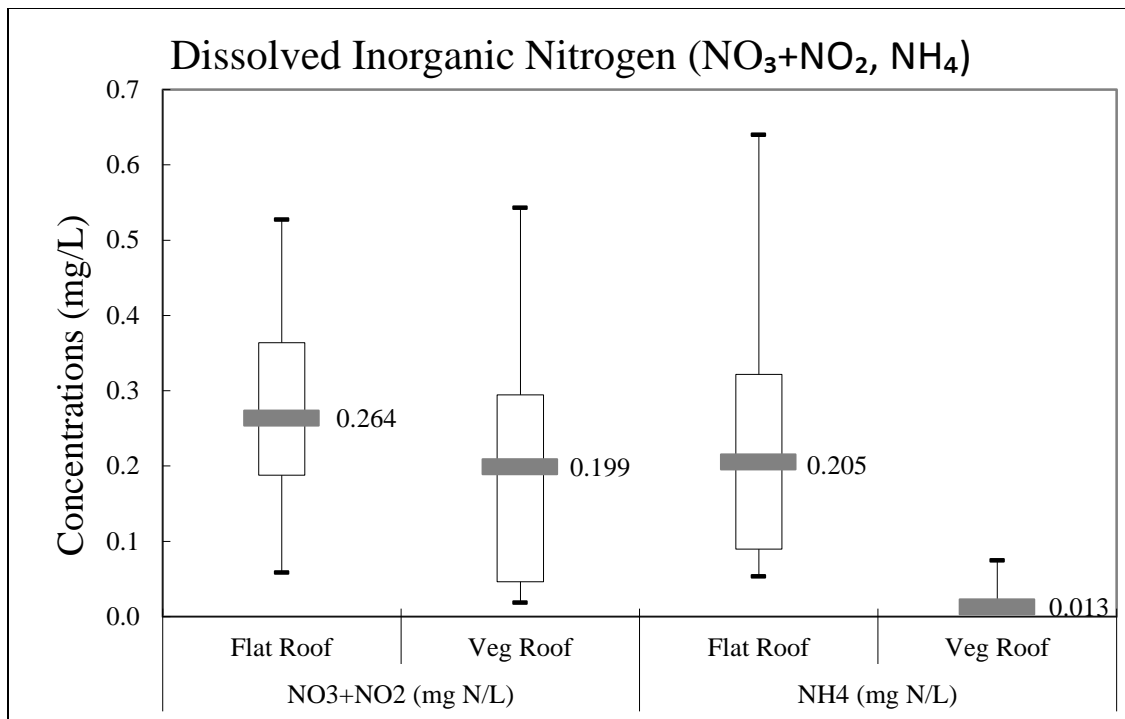
**Figure 2: Box and whisker plots of Total Nitrogen (TN) and Particulate Nitrogen results from conventional flat roof and vegetated green roof comparison study.**



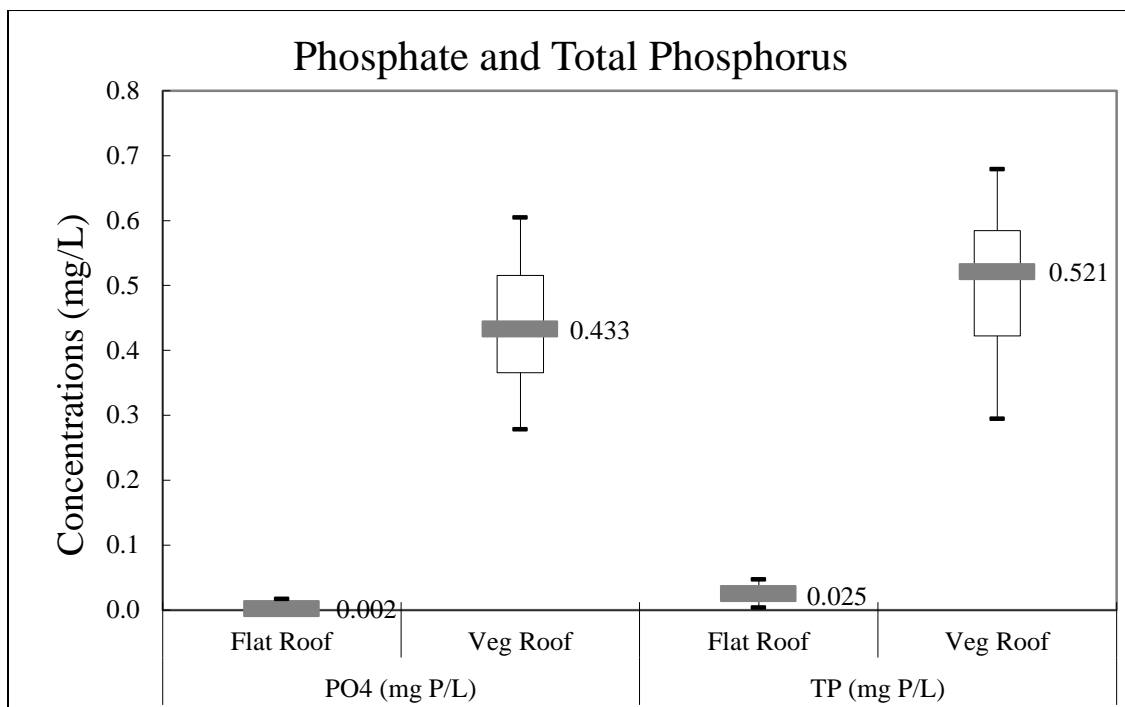
**Figure 3: Box and whisker plots of Total Dissolved Nitrogen (TDN) and Dissolved Organic Nitrogen (DON) results from conventional flat roof and vegetated green roof comparison study.**

**Table 4: Water quality monitoring results for the conventional flat roof and vegetated green roof including nitrate (NO<sub>3</sub>) & nitrite (NO<sub>2</sub>), ammonium (NH<sub>4</sub>), phosphate (PO<sub>4</sub>), and total phosphorus (TP) concentrations.**

Date	NO3+NO2 (mg N/L)			NH4 (mg N/L)			PO4 (mg P/L)			TP (mg P/L)		
	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%	Veg Roof	Flat Roof	RE%
7/11/2013	0.543	0.428	-27%	0.075	0.281	73%	0.605	0.002	-30131%	0.679	0.047	-1347%
7/23/2013	0.312	0.297	-5%	0.014	0.158	91%	0.504	0.002	-25084%	0.576	0.022	-2570%
8/1/2013	0.289	0.230	-26%	0.016	0.094	83%	0.377	0.002	-20766%	0.447	0.041	-998%
8/9/2013	0.033	0.102	68%	0.033	0.076	56%	0.441	0.005	-9393%	0.605	0.035	-1631%
9/12/2013	0.050	0.216	77%	0.011	0.253	96%	0.551	0.009	-6174%	0.578	0.004	-15308%
9/22/2013	0.019	0.058	68%	0.011	0.053	79%	0.426	0.017	-2391%	0.466	0.023	-1947%
10/6/2013	0.158	0.342	54%	0.012	0.443	97%	0.331	0.002	-16456%	0.347	0.023	-1428%
10/31/2013	0.240	0.527	54%	0.010	0.640	98%	0.278	0.002	-13206%	0.295	0.028	-956%
MIN	0.019	0.058	-27%	0.010	0.053	56%	0.278	0.002	-30131%	0.295	0.004	-15308%
25th Q	0.046	0.188	-10%	0.011	0.090	78%	0.366	0.002	-21845%	0.422	0.022	-2103%
MEDIAN	0.199	0.264	54%	0.013	0.205	87%	0.433	0.002	-14831%	0.521	0.025	-1530%
AVERAGE	0.206	0.275	33%	0.023	0.250	84%	0.439	0.005	-15450%	0.499	0.028	-3273%
75th Q	0.295	0.364	68%	0.020	0.322	96%	0.515	0.006	-8588%	0.585	0.036	-1260%
MAX	0.543	0.527	77%	0.075	0.640	98%	0.605	0.017	-2391%	0.679	0.047	-956%



**Figure 4: Box and whisker plots of Nitrate + Nitrite ( $\text{NO}_3+\text{NO}_2$ ) and Ammonium ( $\text{NH}_4$ ) results from conventional flat roof and vegetated green roof comparison study.**



**Figure 5: Box and whisker plots of Phosphate ( $\text{PO}_4$ ) and Total Phosphorus (TP) results from conventional flat roof and vegetated green roof comparison study.**

**Table 5: Real Time water quality monitoring results for the conventional flat roof and vegetated green roof including temperature, specific conductivity, dissolved oxygen and pH.**

	Vegetated Roof				Reference Roof			
Date	Temp (°F)	Spec Cond (uS/cm)	DO (mg/l)	pH	Temp (°F)	Spec Cond (uS/cm)	DO (mg/l)	pH
7/11/2013	53.9	0.072	12.72	6.14	60.8	0.023	5.9	5.18
7/23/2013	36.8	0.147	5.64	5.36	40.5	0.091	5.8	4.31
8/1/2013	65.15	0.074	1.55	4.94	64.41	0.008	2.21	4.78
8/9/2013	66.44	0.041	2.93	4.97	67.63	0.004	3.97	4.42
9/12/2013	68.04	0.044	8.31	5.59	72.57	0.018	7.98	4.14
9/22/2013	50.58	0.042	4.81	5.49	63.9	0.005	1.18	5.07
10/6/2013	68.47	0.066	8.01	6.13	67.05	0.033	8.62	4.73
10/31/2013	61.29	0.181	13.86	6.32	47.48	0.084	9.33	5.41
11/17/2013	50.32	0.136	7.84	5.84	43.2	0.012	6.46	5.4
<b>median</b>	61	0.072	7.84	5.59	64	0.018	5.90	4.78
<b>average</b>	58	0.089	7.30	5.64	59	0.031	5.72	4.83

The vegetative roof systems demonstrated buffering capacity for all measured real-time parameters, temperature, dissolved oxygen (DO) and pH measurements. Average effluent levels from the vegetated roof system were 1 degree F lower, 1.6 mg/L higher and 0.8 points higher respectively for the vegetated roof effluent all representing a positive movement in terms of water quality. The exception is the 0.058 uS/cm increase in the vegetated roof effluent which while still low signifies higher concentrations of ionic elements in the effluent compared to the reference runoff.

## Project Summary

The overall monitoring of the James Hall vegetated roof system and adjacent conventional rubber roof section was successful in attaining information to further the understanding of the non-point source nutrient removal capacity of these systems and their hydrologic functionality. The study provided consistent results for each parameter monitored thereby adding credibility to a relatively small data set. For water quantity parameters, the vegetated roof system demonstrated an average overall reduction in peak flows by 27%. There was no discernable runoff volume reduction which indicates that there is a need for consideration of aggregate depth and storage capacity within the vegetated roof cells to enhance volume reduction. The primary mechanism for volume reduction in vegetated roof systems is evapotranspiration (ET) which is a relatively slow process and likely minimal during precipitation events. Thus the vegetated roof system must have the reservoir capacity to store intercepted water volumes for a time period sufficient to allow ET to reduce the overall volume. The fact that antecedent dry period had no observable effect on volume reductions would indicate that the vegetated roof

system lacks adequate storage capacity. Overall the system demonstrated export of most parameters, but gave promising removals of DIN ( $\text{NO}_3$ ,  $\text{NO}_2$  and  $\text{NH}_4$ ). Water quality results demonstrate that consideration of aggregate type and selection of vegetative species may be important if water quality improvements are expected. Selection of aggregate or growing media with higher cation exchange capacities (CAC) may be necessary to limit the mobilization of in-system positively charged organics such as phosphates.

## **Information Transfer Program Introduction**

The NH WRRC supported two information transfer projects with its 2013 104b funding:

1. New Hampshire WRRC Information Transfer
2. Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program

# New Hampshire WRRRC Information Transfer

## Basic Information

<b>Title:</b>	New Hampshire WRRRC Information Transfer
<b>Project Number:</b>	2008NH97B
<b>Start Date:</b>	3/1/2013
<b>End Date:</b>	2/28/2014
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	01
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	Management and Planning, Education, Non Point Pollution
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	William H. McDowell

## Publications

1. Baillio, J. 2012. 2012. Controls on variability of dissolved greenhouse gas concentration and emissions from small streams in southeastern New Hampshire. M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 111 pages.
2. Daley, M.L. and W.H. McDowell, In Preparation, Human impacts on stream nitrogen chemistry and watershed N retention across a wide range of rural to urban catchments, Ecological Applications.
3. Hope, A.J., W.H. McDowell, W.M. Wollheim, Submitted, Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream, Biogeochemistry.
4. Liptzin, D., M.L. Daley, and W.H. McDowell. Accepted. A comparison of wet deposition collectors at a coastal rural site. Submitted to Water, Air, & Soil Pollution. April 2013.
5. Parham, L. 2012. Spatial and temporal variation in degradation of dissolved organic carbon on the main stem of the Lamprey River. M.S. Dissertation, Department of Natural Resources & the Environment, College of Life Science and Agriculture, University of New Hampshire, Durham, NH, 66 pages.
6. Hope, A.J., W.H. McDowell, W.M. Wollheim. 2013. Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream. Biogeochemistry. September 2013. DOI 10.1007/s10533-013-9900-y
7. Liptzin, D., M.L. Daley, and W.H. McDowell. 2013. A comparison of wet deposition collectors at a coastal rural site. Water, Air, & Soil Pollution. 224(5):1558. 2013.

## **Information Transfer**

Unbridled development and population growth can have detrimental impacts to water resources and ecosystem services. Rapid population growth is occurring in New Hampshire and state regulations, planning board decisions and zoning classifications all attempt to minimize the environmental impact of this rapid population growth. Most land use planning decisions are made at the local level on a town by town basis, often by volunteers who serve on various boards, commissions and committees. Decisions by these various resource managers are often made without a full understanding of the consequences that their decisions will have on water resources or ecosystem services.

This project provided salary for the Center's Director and Associate Director to meet with state representatives, local town officials, watershed groups, school groups, the general public and scientists to discuss WRRC findings that relate to population growth and land use change. The NH WRRC website (<http://www.wrrc.unh.edu/>) is also used to disseminate information on water resources, and is updated and maintained by salary provided by this project. The time of the Director and Associate Director is increasingly spent discussing current and future research in the Lamprey River Hydrologic Observatory, which is partially funded by the longstanding 104B project "Water Quality and the Landscape: Long-term monitoring of a rapidly developing suburban watershed" and on nitrogen dynamics in New Hampshire's Great Bay watershed. On January 10, 2014 the NH WRRC totally funded and organized the **Seventh Annual Lamprey River Symposium** (see also below). Presentations focused on water quality, hydrology, stormwater, climate and landuse change, aquatic species and habitat, watershed planning and nitrogen cycling in coastal New Hampshire. The symposium attracted approximately 100 attendees, including scientists, regional leaders, town officials, members of state agencies, and federal agencies. The agenda can be found on the NH WRRC Lamprey River Hydrologic Observatory Symposium [website](#). This annual symposium and other discussions in which the Center's Director and Associate Director participate further the research and information transfer goals of the NH WRRC.

### **2013 Information Transfer Activities Supported by Section 104b Funding and Matching Funds**

#### **Data for Public Water Supplies**

The NH WRRC's long-term water quality data on the rapidly developing suburban Lamprey River watershed is available to towns as they investigate new potential sources for public water supply. Both Newmarket and Durham, NH have investigated using the Lamprey River to artificially recharge water supply aquifers to meet the town's water supply needs. The NH WRRC has provided both towns and their consulting firm long-term water quality data on the Lamprey River to inform the water supply decision-making processes. As more towns in the future look to the Lamprey for water supply, the long-term dataset provided by the NH WRRC will become increasingly valuable.

## **Nitrogen Data in New Hampshire's Great Bay watershed**

Over the five years, there has been significant focus on nitrogen loading to New Hampshire's largest estuary, the Great Bay estuary, and the impairment to aquatic life it has caused. In August 2009, Great Bay, Little Bay and the tidal rivers were added to the New Hampshire 2008 303d list of impaired waters rendering them in violation of the federal Clean Water Act. Based on the most recent "State of Our Estuaries Report" prepared by the Piscataqua Region Estuaries Partnership (PREP 2013), 32% of the nitrogen entering Great Bay and Little Bay is from point sources; the majority (68%) enters via non-point sources of pollution. The Lamprey River is the largest tributary to Great Bay, and thus the long-term data provided by the NH WRRC from the LRHO are of considerable value for watershed management. The NH WRRC provides the best dataset in NH for assessing the spatial and temporal variability in N concentrations and export in response to suburbanization and changes in land use. These 13+ years of data will be instrumental in assessing the success of current and future efforts to reduce non-point sources of nitrogen pollution reaching Great Bay. There is much interest in LRHO datasets from NH Department of Environmental Services (DES), PREP, the Environmental Protection Agency (EPA) and other municipal, regional, state and federal agents. Many of the presentations and meetings listed below focused on transferring information on nitrogen cycling to stakeholders throughout NH's coastal watershed and beyond. The NH WRRC has received several phone calls to discuss the Great Bay nitrogen issue and also the EPA's draft National Pollutant Discharge Elimination System (NPDES) permits that limit nitrogen in wastewater treatment plant effluent to 3 mg/L in several seacoast communities.

## **Symposia, Conferences and Seminars Organized and Funded**

The NH WRRC funded and organized the "**Seventh Annual Lamprey River Symposium**" held January 10, 2014 in Durham, NH. The symposium is dedicated to exchanging the results of recent research on the water quality, hydrology, water resources issues, and management of the Lamprey River basin. The Symposium is a vehicle for researchers to share data and insights with other researchers, as well as those in the management and policy arena who would benefit from exposure to the latest research on the watershed. The symposium drew approximately 100 attendees, including researchers, legislators, water system operators, town officials, regional leaders and government officials. The symposium contained 12 presentations split up over three sessions. There was a break out session on sensors that collect 'real-time' water-quality data year-round and a poster session during lunch (5 posters and displays were exhibited). The day ended with an open discussion on research priorities in the Lamprey watershed and southeast NH. This event was mostly funded and organized by the NH WRRC. Staff from UNH cooperative extension and Great Bay National Estuarine Research Reserve helped moderate the open discussions and NH EPSCoR assisted with registration and printing. Survey results indicate that 94% of the attendees found the topics covered to be either helpful or very helpful.

The NH WRRC sponsored the “**NH Water and Watershed Conference**” in Plymouth, NH on March 22, 2013. This event was designed to meet the information and networking needs of lake, river, and watershed groups; environmental organizations; volunteer monitors; municipal board and staff members; elected officials; local and regional planners; policy makers; scientists; educators; consultants and students. The focus for the 2013 conference was to enhance capacity to understand, protect, and manage New Hampshire's water resources. The NH WRRC co-Sponsored this conference along with Plymouth State University and the Center for the Environment, NH EPSCoR, NH DES, US Geological Survey New England Water Science Center, Tighe & Bond Inc. and the Society for Ecological Restoration, New England Chapter. The conference contained 5 concurrent sessions including watershed planning and management, water quality and quantity data, using new sensor technology for monitoring, ecosystem services, education and outreach, climate change response and legal authority on climate adaptation. The conference drew approximately 250 people, including researchers, legislators, water system operators, land use planners, and government officials.

### **Publications**

Daley, M.L. and W.H. McDowell. In Preparation. Human impact on N chemistry in streams visible at lowest population density in a range of suburbanizing basins. In Preparation for Ecological Applications.

Hope, A.J., W.H. McDowell, W.M. Wollheim. 2013. Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream. Biogeochemistry. September 2013. DOI 10.1007/s10533-013-9900-y

Liptzin, D., M.L. Daley, and W.H. McDowell. 2013. A comparison of wet deposition collectors at a coastal rural site. Water, Air, & Soil Pollution. 224(5):1558. 2013.

### **Conference Proceedings & Abstracts:**

Daley, M.L. and McDowell, W.H. 2013. Non-Point Nitrogen Sources and Transport Pathways in the Great Bay Watershed. NH Water and Watershed Conference. Plymouth, NH. March 2013.

Koenig, L. E.; Baumann, A. J.; McDowell, W. H. 2013. Improving automated phosphate analysis to eliminate silicate interference. (Abstract ID: 8116). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013

McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? European Geophysical Union Annual Meeting, Vienna, Austria April 2013 (invited keynote presentation).

McDowell, W.H. 2013. Soils and stream chemistry: When, where and why are they linked? University of Amsterdam, Amsterdam, Netherlands. April 2013.

McDowell, W. G.; Rosemond, A. D.; McDowell, W. H.; Byers, J. E. 2013. Impacts, dead or alive: Effects of mass mortality of an abundant invasive species on ecosystem function. (Abstract ID: 7715). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013.

McDowell, W.H. 2013. Linkages between organic matter and carbon levels in surface waters and soils. UNESCO IHE Ecohydrology. Delft, Netherlands. June 2013.

Price, A. J.; Wollheim, W. M.; Mulukutla, G.; and McDowell, W. H. 2013. Headwater catchment nitrogen flux and storm response among land use types through seasons. (Abstract ID: 8050). Annual Meeting of the Society for Freshwater Science, Jacksonville, FL, May 2013.

Smith, Thor E., McDowell, William H., Wollheim, Wilfred M., Daley, Michelle, Mulukutla, Gopal, Baumann, Adam J., Snyder, Lisle, and Price, Allison. 2013. Sampling the Lamprey River watershed across space and time; New data collection efforts toward understanding nitrogen sources. The Geological Society of America Northeastern Section - 48th Annual Meeting. Omni-Mount Washington Hotel, Bretton Woods, New Hampshire. March 2013. *Abstract accepted but not presented due to federal employee travel restrictions.*

### **Presentations/Information Transfer**

Cripps, M.L. and Daley, M.L. 2013. Ossipee watershed: ten years of water monitoring. Presentation to Green Mountain Conservation Group (GMCG) Research Committee, Watershed Management Plan Steering Committee, Water Quality Monitoring Volunteers and GMCG Board, Freedom Village, NH. May 15, 2013.

Daley, M.L. and McDowell, W.H. 2013. Aquatic Sensor Networks, Ecosystem Function and Management. NH EPSCoR all hands meeting. Durham, NH. March 28, 2013.

Daley, M.L. 2013. Water Quality: How do you know if it is good or bad? Kingston, NH High School presentation to 180 high school students (9 groups of 20, 20 min each). June 4, 2013.

Daley, M.L. 2013. Non-point nitrogen research in the Lamprey and Great Bay watershed. Great Bay boat tour with the NH House of Representatives Resources, Recreation and Development Committee. June 15, 2013.

Daley, M.L. 2013. Research on nitrogen in the Great Bay watershed: Learn how diffuse sources of nitrogen pollution travel from our communities to the Great Bay. Scheduled for Contemporary Coastal Issues sail on the Gundalow in Portsmouth, NH on August 28, 2013. but sail was cancelled last minute due to fog. Will reschedule.

Daley, M.L. Nitrogen Sources and Transport Update. Nitrogen Sources Collaborative Advisory Board. Lee, NH. August 29, 2013.

- Daley, M.L. 2013. Water Quality Research in the Lamprey River Hydrologic Observatory. Presentation to University of New Hampshire undergraduate class: Studio Soils. October 25, 2013.
- Daley, M.L. 2013. Presentation on “What it’s like to be a scientist and how I became a water quality scientist” to 40 6-8<sup>th</sup> graders from Epping Middle School during their visit to the University of New Hampshire. November 15, 2013.
- Daley, M.L. 2013. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Durham-UNH Integrated Permit and Planning Technical Advisory Committee. Oct 29, 2013.
- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport project results to members (Allison Watts and Paul Stacey) of the Water Integration for Squamscott-Exeter (WISE) NERRS Science Collaborative project to aid the project team in designing a water quality monitoring program. January 17, 2014.
- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Laura Byergo and Peter Wellenberger from Great Bay Stewards to discuss how this project might inform site locations chosen for the Great Bay Stewards “soak up the rain” effort. Jan 31, 2014
- Daley, M.L. 2014. Presented preliminary Great Bay N Sources and Transport NERRS Science Collaborative project results to Mark Zankel and Peter Steckler from The Nature Conservancy (TNC) to discuss how the project can inform the next version of the TNC Land Conservation Plan for New Hampshire's Coastal Watershed. February 26, 2014.
- Kobylinski, A. 2013. Gave tour of Thompson Farm AIRMAP facility and demonstrated precipitation collection form a wet-only collector on top of an 80 foot tower to 10 senior environmental chemistry students from Phillip’s Exeter Academy. Durham, NH. April 16, 2013.
- Koenig, L. 2013. Led 27 Dover High School students on a field trip to assess water quality in an urban stream draining the University of New Hampshire and to tour the UNH Water Quality Analysis Laboratory. May 30, 2013.
- McDowell, W.H. and M.L. Daley. 2013. Nonpoint nitrogen sources and transport in New Hampshire’s Great Bay watershed. Presented at Nitrogen in Stormwater: Sources and Solutions Workshop, NH DES, Portsmouth, NH May 2013.
- May 16, 2013 Shared Great Bay N stormwater presentation with Carl Delo from EPA
- Swan, K. 2013. Spoke to students from the Stream Safari program at McLaughlin Middle School in Manchester, NH on “Why I became a scientist, what I do each day for work and how scientists monitor stream quality”. November 13, 2013.

Wollheim, W.W., A. Price, R. Careyu, G. Mulukutla, and W.H. McDowell. 2013. Storm event nutrient monitoring in river networks. Presented at Nitrogen in Stormwater: Sources and Solutions Workshop, NH DES, Portsmouth, NH May 2013.

## **Press Releases**

Daley, M.L. 2013. Clean water: It's everyone's responsibility to reduce pollution and properly manage New Hampshire's land areas to protect our water resources. Blog June 18, 2013. <http://ecosystemsandsociety.blogspot.com/2013/06/clean-water-its-everyones.html>

Forester Courtland, V. 2013. Upstream Impact: Graduate Students Inspire the Next Generation of STEM Scholars. UNH Today. May 30, 2013. [http://www.unh.edu/unhtoday/2013/05/upstream-impact?utm\\_source=Team+Update%3A+Ecosystems+and+Society+05%2F31%2F2013&utm\\_campaign=Team+Update&utm\\_medium=email](http://www.unh.edu/unhtoday/2013/05/upstream-impact?utm_source=Team+Update%3A+Ecosystems+and+Society+05%2F31%2F2013&utm_campaign=Team+Update&utm_medium=email). Koenig, L. featured in article.

Gillies, J. 2014. New Hampshire stream monitoring network tracks Great Bay nutrient loading. Environmental Monitor. January 16, 2014. <http://www.fondriest.com/news/great-bay-new-hampshire-stream-monitoring.htm>. McDowell, W.H. interviewed for article.

Morrill, D. 2013. Dogs who really know their business: Trained to find human waste in waterways. Foster's. Aug 2, 2013. [http://www.fosters.com/apps/pbcs.dll/article?AID=/20130802/GJNEWS\\_01/130809822](http://www.fosters.com/apps/pbcs.dll/article?AID=/20130802/GJNEWS_01/130809822). Daley, M.L. included in article.

Nilsen, E. 2013. New Hampshire Pubic Radio "Statewide Project Looks At Ecosystems and Climate Change." August 21, 2013. <http://nhpr.org/post/statewide-project-looks-ecosystems-and-climate-change>. Snyder, L. interviewed for article.

Potter, J.D., Godbois, A., Snyder, L. 2013. Cutting edge environmental monitoring comes to New Hampshire. Blog July 17, 2013. <http://ecosystemsandsociety.blogspot.com/2013/07/cutting-edge-environmental-monitoring.html>.

## **Meetings attended**

Daley, M.L. 2013. Attended Integrated Watershed Management in the Great Bay Watershed workshop. Durham, NH. April 5, 2013.

Daley, M.L. 2013. NSF Becoming the Messenger Workshop. Durham, NH. April 10-11, 2013.

Daley, M.L. 2013. NH Water and Watershed Planning Meeting. Conference call. March 5, 2013.

Daley, M.L. 2013. Nitrogen in Stormwater: Sources and Solutions Workshop. Planning Meeting. April 16, 2013.

Daley, M.L. 2013. NH Water and Watershed Planning Meeting. Conference call. April 24, 2013.

Daley, M.L., McDowell, W.H. and Potter, J.D. 2013. The Future of Great Bay Public Forum. Greenland, NH. April 30, 2013.

Daley, M.L. 2013. Great Bay Nitrogen Non-Point Source Study Release & Workshop. Portsmouth, NH. May 16, 2013.

Daley, M.L. 2013. Potential Edge of Field Monitoring with Natural Resource Conservation Service. Durham, NH. May 30, 2013.

Daley, M.L. 2013. Great Bay comprehensive monitoring meeting. Durham, NH. June 14, 2013.

- Daley, M.L. 2013. Meet w Deana Aulisio to discuss nitrogen metabolism in Durham, NH. June 24, 2013.
- Daley, M.L. 2013. Canine detection in Durham, NH. August 1, 2013.
- Daley, M.L. 2013. Great Bay comprehensive monitoring meeting. Greenland, NH. August 27, 2013.
- Daley, M.L. 2013. Durham/UNH Oyster River Watershed NPS Model TAC Mtg. Durham, NH October 9, 2013.
- Daley, M.L. 2013. Met with Elizabeth Durfee, early career water resources planner, to discuss local water issues in NH and potential planning opportunities. November 8, 2013.
- Daley, M.L. 2013. Piscataqua Region Estuaries Partnership Technical Advisory Committee meeting. Durham, NH November 17, 2013.

# Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program

## Basic Information

<b>Title:</b>	Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program
<b>Project Number:</b>	2012NH174B
<b>Start Date:</b>	3/1/2013
<b>End Date:</b>	2/28/2014
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	001
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Water Quality, Non Point Pollution, Management and Planning
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Jeffrey Schloss

## Publications

1. Craycraft, Robert and Jeffrey A. Schloss. 2012. Baboosic Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 138 pps.
2. Craycraft, Robert and Jeffrey A.Schloss. 2012. Bow Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 114 pps.
3. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Chocorua Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 80 pps.
4. Craycraft, Robert and Jeffrey A.Schloss. 2012. Conway Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH.92 pps.
5. Craycraft, Robert and Jeffrey A.Schloss. 2012 Crystal Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 76 pps.
6. Craycraft, Robert and Jeffrey A.Schloss. 2012 Goose Pond Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 78 pps.
7. Craycraft, Robert and Jeffrey A.Schloss. 2012. Great East Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 106 pps.
8. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Kanasatka Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 86 pps.
9. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lovell Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 86 pps.

## Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program

10. Craycraft, Robert and Jeffrey A.Schloss. 2012. Mendums Pond Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 80 pps.
11. Craycraft, Robert and Jeffrey A.Schloss. 2012. Merrymeeting Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 86 pps.
12. Craycraft, Robert and Jeffrey A.Schloss. 2012. Milton Ponds (Depot, Townhouse and Northeast) Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 98 pps.
13. Craycraft, Robert and Jeffrey A.Schloss. 2012. Mirror Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 76 pps
14. Craycraft, Robert and Jeffrey A.Schloss. 2012. Naticook Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 80 pps
15. Craycraft, Robert and Jeffrey A.Schloss. 2012. Nippo Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 78 pps
16. Craycraft, Robert and Jeffrey A.Schloss. 2012. North River Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 72 pps
17. Craycraft, Robert and Jeffrey A.Schloss. 2012. Silver Lake (Madison) Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 98 pps
18. Craycraft, Robert and Jeffrey A.Schloss. 2012. Highland Lake (Windham ME) Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 106 pps
19. Craycraft, Robert and Jeffrey A.Schloss. 2012. Squam Lakes Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 160 pps
20. Craycraft, Robert and Jeffrey A.Schloss. 2012. Sunset Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 63 pps
21. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Wentworth and Crescent Lake Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 108 pps
22. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnepesaukee-Alton Bay Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 93 pps
23. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnepesaukee-Meredith Bay Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 64 pps
24. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnepesaukee-Saunders Bay Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 110 pps
25. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnepesaukee-Saunders Bay Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 110 pps
26. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnepesaukee-Tuftonboro Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 110 pps

## Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program

27. Craycraft, Robert and Jeffrey A.Schloss. 2012. Lake Winnisquam Annual Lake Report for 2011. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 74 pps
28. Craycraft, Robert and Jeffrey A. Schloss. 2013. Baboosic Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 132 pps.
29. Craycraft, Robert and Jeffrey A.Schloss. 2013. Bow Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 108 pps.
30. Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Chocorua Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 82 pps.
31. Craycraft, Robert and Jeffrey A.Schloss. 2013. Conway Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH.92 pps.
32. Craycraft, Robert and Jeffrey A.Schloss. 2013 Crystal Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 82 pps.
33. Craycraft, Robert and Jeffrey A.Schloss. 2013. Great East Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 114 pps.
34. Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Kanasatka Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 94 pps.
35. Craycraft, Robert and Jeffrey A.Schloss. 2013. Lovell Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 84 pps.
36. Craycraft, Robert and Jeffrey A.Schloss. 2013. Mendums Pond Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 80 pps.
37. Craycraft, Robert and Jeffrey A.Schloss. 2013. Merrymeeting Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 96 pps.
38. Craycraft, Robert and Jeffrey A.Schloss. 2013. Michawanic Pond Data Review (January 22, 2014). New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 14 pps.
39. Craycraft, Robert and Jeffrey A.Schloss. 2013. Milton Ponds (Depot, Townhouse and Northeast) Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH..96 pps.
40. Craycraft, Robert and Jeffrey A.Schloss. 2013. Naticook Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 88 pps.
41. Craycraft, Robert and Jeffrey A.Schloss. 2013. North River Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 84 pps.
42. Craycraft, Robert and Jeffrey A.Schloss. 2013. Silver Lake (Madison) Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 102 pps.
43. Craycraft, Robert and Jeffrey A.Schloss. 2013. Squam Lakes Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 140 pps.

## Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program

44. Craycraft, Robert and Jeffrey A.Schloss. 2013. Sunset Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 90 pps.
45. Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Winnisquam Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 90 pps.

## **2013NH174B**

### **Participatory Water Quality Assessment Through the NH Lakes Lay Monitoring Program**

#### **Problem:**

The fresh waters of New Hampshire represent a valuable resource contributing to the State's economic base through recreation, tourism, real estate revenues and taxes. In addition some lakes and rivers serve as current or potential drinking water reservoirs/supplies. For most residents our generally pristine waters help to insure a high quality of life. However, New Hampshire currently leads all of the New England states in the rate of new development and redevelopment (Society for the Preservation of New Hampshire Forests, Governor's Office of Energy and Planning). The long-term consequences of the resulting pressure and demands on the state's precious water resources remain unknown. Of particular concern is the response of our waters to increasing non-point source pollutant loading due to watershed development and land use activities. Local citizens, lake/watershed associations and local decision-makers remain in dire need of additional information required for the intelligent management of our water resources on the local level. State agencies need to be better informed on water quality changes and trends. Limited financial resources do not allow for adequate monitoring of these waters by state or federal agency personnel,

The recent increase of infestations of invasive species such as variable water milfoil as well as the proliferation of blue green bacteria blooms, which can leach dangerous toxins impacting humans and wildlife, has threatened the water quality and has limited or restricted use of NH waters at an increasing rate. There is still no mechanism for successful eradication of milfoil and we are just beginning to understand the conditions that favor blue green bacteria blooms and their ecological impacts through cutting edge research by UNH faculty and students.

#### **Objectives:**

**The funds provided by the WRRC provided continued partial support of our long term citizen science participatory monitoring effort, the NH Lakes Lay Monitoring Program (LLMP).** Additional support for this effort is provided by UNH Cooperative Extension, The UNH College of Life Sciences and Agriculture, USDA National Institute of Food and Agriculture, New Hampshire Department of Environmental Services (NH DES; from US EPA section 319 funding) and from towns, municipalities and lake associations throughout the state.

- 1- The continued collection and analysis of long-term water quality data in selected watersheds.
- 2- The dissemination of the results of the analysis to cooperating agencies, water managers, educators and the public on a local, statewide and regional basis.
- 3- To offer undergraduate and graduate students the opportunity to gain hands-on experience in water quality sampling, laboratory analysis, data management and interpretation.
- 4- To further document the changing water quality in a variety of watersheds throughout the state in the face of land use changes and best management efforts.

## **Methods**

Lake and stream monitoring through the LLMP generally involved a minimum of monthly sampling starting at spring runoff through to lake stratification and weekly to bi-weekly sampling through to fall mixis. Water clarity, chlorophyll a, acid neutralizing capacity, dissolved organic color, dissolved oxygen and nutrients (total N, total P and nitrate) will be the default suite of parameters measured for lakes while nutrients, turbidity, dissolved organic color and flow will be the parameters of choice for the lake tributary work. On occasion, student field teams traveled to join the volunteer monitors to perform quality assurance checks and do more in-depth analysis and lake profiling. All LLMP field sampling and laboratory analysis follows approved Quality Assurance Projects Plans and Site Specific Project Plans reviewed by NH DES and US EPA New England and are on file with both agencies.

As stated above the primary scope of this project was to maintain the long-term data collection effort of the LLMP and support information transfer for informed local decision making regarding water resources.

## **Principal findings and significance**

Focus of this year's efforts was on the Newfound Lake Watershed, Wentworth Lake and the Ossipee Lake watershed.

These research findings continued to support an innovative approach used by the Newfound Lake Regional Association to have the watershed towns consider changing their current development ordinances to utilize variable buffer width requirements based on slope. To date 2 towns have incorporated this recommendation and additional towns are considering the measure. Volunteer data were used to help calibrate a watershed land use nutrient loading model as well as a lake response model for the resulting phosphorous nutrient loading.

The Town of Wolfeboro and Lake Wentworth Foundation developed a Watershed Management Plan to protect Lake Wentworth and Crescent Lake. Tributary and in-lake water quality data collected through the NH LLMP were used to calibrate a watershed land use nutrient loading model as well as a lake response model for the resulting phosphorous nutrient loading. A second phase of the project is currently underway to implement Best Management Practices to control sediment and nutrient runoff into Lake Wentworth. The resulting information is also being used by the Town of Wolfeboro, the Lake Wentworth Association and the Lake Wentworth Foundation to consider regulation and zoning amendments, to target educational/outreach efforts and to continue to prioritize problem areas for remediation.

## **Publications and Presentations**

### Reports:

Craycraft, Robert and Jeffrey A. Schloss. 2013. Baboosic Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 132 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Bow Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 108 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Chocorua Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 82 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Conway Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 92 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Crystal Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 82 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Great East Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 114 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Kanasatka Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 94 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Lovell Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 84 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Mendums Pond Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 80 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Merrymeeting Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 96 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Michawanic Pond Data Review (January 22, 2014). New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 14 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Milton Ponds (Depot, Townhouse and Northeast) Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 96 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Naticook Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 88 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. North River Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 84 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Silver Lake (Madison) Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 102 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Squam Lakes Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 140 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Sunset Lake Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 90 pps.

Craycraft, Robert and Jeffrey A.Schloss. 2013. Lake Winnisquam Annual Lake Report for 2012. New Hampshire Lakes Lay Monitoring Program; UNH Center for Freshwater Biology and UNH Cooperative Extension. Durham, NH. 90 pps.

#### Presentations:

Craycraft, Robert. 2013. Lake Winnepesaukee Mount Washington Cruise water quality talk. Water quality and economic value. May 22, 2013 Attendance: 22.

Craycraft, Robert. 2013. Lake Kanasatka Watershed Association Annual Meeting: Lake Kanasatka water quality, past, present and future. June 13, 2013. Attendance: 50.

Craycraft, Robert. 2013. Lake Winnepesaukee Mount Washington Cruise water quality talk: Lake Winnepesaukee water quality overview and water quality threats. August 7, 2013. Attendance: 13.

Craycraft, Robert 2013. New Hampshire Coverts Program lecture: Water quality overview and threats to New Hampshire lakes. September 20, 2013. Attendance: 22.

Craycraft, Robert 2013. University of New Hampshire Thompson School Forest Technology class lecture: Macroinvertebrates and their interrelationship with the forested landscape. September 30, 2013. Attendance: 18.

## **Outreach/Information Transfer**

July 25, 2013. Guest of the New Hampshire Lakes Management Advisory Committee. Discussed water quality monitoring in the Newfound Lake watershed as part of a watershed management planning effort. (Craycraft)

October 30, 2013- Guest lecture-for Marine Ecology and Freshman Biology (MEFB) class. Introduction to Water Resources through the Lakes lay Monitoring Program and NH Lakes. (Craycraft)

## **Students Supported**

While no WRRC support was provided for direct undergraduate student support, the following students were indirect beneficiaries of WRRC support to the NH LLMP:

### **Undergraduate Students**

Amy Arsenault	Environmental Conservation	Senior (Spring 2014 Grad)
Casey Chalmers	Environmental Conservation	Senior (Spring 2014 Grad)
Hannah Johnson	Environmental Conservation	Senior (Spring 2013 Grad)
Ryan Ross	Microbiology	Junior
Will Taveras	Civil Engineering	Junior
Jessica Waller	Marine Biology	Senior (Spring 2013 Grad)

### **Graduate Students Supported**

Jeff Schloss	Natural Resources and Environmental Studies	PhD candidate
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## **Faculty Staff Supported**

Directly: Robert Craycraft, Educational Program Coordinator, LLMP UNH Cooperative Extension.

Indirectly: Jeff Schloss- Extension Professor in Biological Science

# **USGS Summer Intern Program**

None.

<b>Student Support</b>					
<b>Category</b>	<b>Section 104 Base Grant</b>	<b>Section 104 NCGP Award</b>	<b>NIWR-USGS Internship</b>	<b>Supplemental Awards</b>	<b>Total</b>
<b>Undergraduate</b>	15	0	0	4	19
<b>Masters</b>	6	0	0	3	9
<b>Ph.D.</b>	2	0	0	1	3
<b>Post-Doc.</b>	0	0	0	1	1
<b>Total</b>	23	0	0	9	32

## **Notable Awards and Achievements**